NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE

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IMPACT STRENGTH AND FLEXURAL PROPERTIES OF LAMINATED PLASTICS AT HIGH AND LOW TEMPERATURES

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National Bureau of Standards

Washington
August 1946

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SUMMARY

The Izod-impact strengths and flexural properties of several types of plastic laminates, which are either in use or have potential application in aircraft structures and parts, were determined at different temperatures in the range of -70° to 200° F.

The materials investigated were unsaturated-polyester laminates reinforced with glass fabric and phenolic laminates reinforced with asbestos fabric, high-strength paper, rayon fabric, and cotton fabric. Both high-pressure and low-pressure types of cotton-fabric phenolic laminates were included.

The impact strength of specimens tested flatwise at 77° F was 4 to 7 foot-pounds per inch of notch for all the laminates except the glass fabric and rayon fabric laminates. These two materials had impact strengths of 31 and 17 foot-pounds, respectively, at 77° F. The high-strength-paper, rayon-fabric, and asbestos-fabric phenolic laminates showed small changes in impact strength between -70° and 200° F. Cotton-fabric phenolic laminates showed pronounced decreases in impact strength at the low temperature and small changes between 77° and 200° F. The glass-fabric unsaturated-polyester laminates had increased impact strengths at the low temperature.

The flexural strengths and moduli of elasticity of all the materials increased with change in the test temperature from 77° to -70° F. Under exposure to a 200° F temperature, all materials except the asbestos-fabric laminate lost 30 to 40 percent of their flexural strength at 77° F and the moduli of elasticity of all the materials, except the asbestos-fabric and one cotton-cloth phenolic laminate, decreased about 20 percent.

Tests made at room temperature after heating the materials at 200° F for 24 hours indicate that prolonged heating with consequent loss of moisture content and further cure of the resin may offset the effect of high temperature alone. In flexural tests made at 150° F and 90 percent relative humidity two laminates showed considerable loss in strength.

INTRODUCTION

A knowledge of the effect of temperature on the strength properties of plastics is of considerable importance in application of the materials for aircraft structural purposes. Results obtained by various investigators (references 1, 2, and 3) on plastic materials indicate that considerable variation may be expected.

Oberg, Schwartz, and Shinn (reference 2) reported variations of 10 to 30 percent in the tensile and flexural properties of grades C, L, and XX phenolic laminates for the range -38° to 78° F. Data on resin-bonded plywood and compreg also are included.

Norelli and Gard (reference 3) reported data for tensile, compressive, and shear strengths and tensile moduli of elasticity for various phenolic laminates for temperatures ranging from -67° F to as high as 392° F in some instances. They concluded that the percentage change in strength for cellulose-filled plastics is greater than for the mineral-filled plastics.

Meyer and Erickson (reference 4) determined the mechanical properties of high-strength paper-base phenolic laminates for temperatures from -69° to 200° F. For this temperature range they found large variations in tensile, compressive, and flexural strengths and somewhat smaller variations in modulus of elasticity. The strength and modulus-of-elasticity values diminished with increasing temperature.

In recent investigations by the Naval Air Experimental Station (reference 5) considerable data has been obtained at 77° and 160° F on the mechanical properties of a variety of plastic laminates. The ultimate strength and modulus-of-elasticity values were generally lower at the higher temperature but the percentage changes varied greatly for the different materials.

Izod-impact test data reported by Fuller (reference 6) for grades L and XX phenolic laminates and for a glass-cotton-fabric phenolic laminate indicate an increase in Izod-impact strength with temperature for the cellulose-filled resin and an opposite trend for the glass-cotton-fabric laminate for the range -67° to 158° F. Shinn (reference 7) found that the Izod-impact strength of paper and cotton-fabric phenolic laminates increased with temperature over the temperature range -67° to 158° F and a similar trend was observed for paper and cotton-fabric allyl laminates between -67° and 77° F.

The present investigation was undertaken to obtain the impact, flexural, tensile, and compressive strength properties of representative laminates in the temperature range -70° to 200° F. Since testing at these temperature conditions presents many problems not met in testing at room temperature, a major part of the project was concerned with the development of apparatus and techniques. This report summarizes the results of Izod-impact and flexural tests on the selected materials. Both flexural strength and flexural-modulus-of-elasticity data were obtained in the flexural tests.

This investigation, conducted at the National Bureau of Standards, was sponsored by and conducted with the financial assistance of the National Advisory Committee for Aeronautics.

The courtesy of the Army Air Forces, Bakelite Corporation, Consolidated Water Power and Paper Company, Formica Insulation Company, Plaskon Division of the Libbey-Owens-Ford Glass Company, and the Synthane Corporation in furnishing materials for use in this investigation is gratefully acknowledged. The cooperation of H. J. Kaiser, R. W. Thiebeau, G. E. Brenner, and P. Pfaff of the National Bureau of Standards Instrument Shop in the design and construction of the flexural apparatus and the preparation of the test specimens also is appreciated.

MATERIALS

The materials selected for testing included commercial grades of high- and low-pressure cotton-fabric phenolic laminates, an asbestos-fabric grade AA phenolic laminate, a high-strength-paper phenolic laminate, a rayon-fabric phenolic laminate, two experimental phenolic laminates made with high pressure and low pressure, respectively, using the same grade C cotton fabric as filler, and two glass-fabric laminates bonded with the same unsaturated polyester resin. The materials were supplied in nominal 1/8- and 1/2-inch thicknesses. A detailed description of the materials is contained in table I.

DEFINITIONS

Izod-impact strength:

Energy to break the specimens divided by the dimension along the notch of the specimen

Flexural properties for beam of rectangular cross section subjected to a concentrated load P at midspan:

Extreme fiber stress (at midspan):

$$S = \frac{3}{2}\,\frac{PL}{bd^2}$$

where

P load

L span or distance between supports

b breadth of beam

d depth of beam

Flexural strength:

$$S_r = \frac{3}{2}\,\frac{P_m L}{bd^2}$$

where P_m is maximum load and other quantities are as defined previously

Flexural modulus of elasticity:

$$E = \frac{L^3}{4bd^3}\,\frac{P}{x}$$

where x is the deflection at midspan and the other quantities are as defined previously

Initial modulus of elasticity E_i is obtained when the initial slope of the load-deflection curve is used for P/x.

Secant modulus of elasticity for the stress range 0 to S_1 is obtained from the above formula for E, using the value of P_1 corresponding to S_1 and obtaining the corresponding deflection x_1 from the load-deflection curve.

Specific flexural strength:

$$\frac{S_r}{(\text{Specific gravity})^2}$$

Specific modulus of elasticity:

$$\frac{E}{(\text{Specific gravity})^3}$$

where the specific gravity is taken as equal numerically to the density in grams per cubic centimeter.

Statistical terms:

Mean value:

The arithmetic mean of a set of measurements

Standard error of the mean (usually called the "standard error" if no other statistic is referred to at the same time):

$$S.E. = \sqrt{\frac{r_1^2 + r_2^2 + r_3^2 + \ldots + r_i^2 + \ldots + r_n^2}{n(n-1)}}$$

where

r_i the difference between the i^{th} measurement and the mean value

n the number of measurements

Standard error for the difference of two means:

$$S.E._D = \sqrt{(S.E._1)^2 + (S.E._2)^2}$$

where

$S.E._1$ standard error for first mean

$S.E._2$ standard error for second mean

Criterion for significant difference between two means (as for example when comparing the mean of a group of treated specimens with the mean of a similar group of untreated specimens):

If the difference of the two means exceeds three times $S.E._D$, the difference is considered significant.

APPARATUS AND TEST PROCEDURE

The testing procedures outlined in Federal Specification L-P-406a (reference 8) were followed as closely as possible. The specimens, however, were not polished with fine emery paper after machining. The flexure specimens of one glass-filled laminate U2 were cut with a diamond abrasive saw. The impact and flexure specimens of the other glass-filled laminate AB2 were machined with carbide-tipped tools. Specimens of all other materials were machined with high-speed steel tools which gave a finish considered satisfactory.

Specimens tested at 77° F and 50 percent relative humidity were conditioned at least 96 hours prior to test. Specimens tested at other temperatures were first conditioned the same as the 77° F specimens and then were kept at the testing temperature for 24 ± 2 hours prior to test.

Impact Strength

The impact tests were made according to Method 1071 in Federal Specification L-P-406a, using a Baldwin-Southwark pendulum-type Izod-impact machine which had ranges of 2, 8, and 16 foot-pounds. The specimens were centered and the notch located properly with alinement jigs.

The tests were made at temperatures of -70°, 0°, 77°, and 200°F. The relative humidity was controlled at 50 percent in testing at 77° F and was not controlled at the other temperatures. The tests at 0° and 77° F were made in rooms controlled at these temperatures. For the -70° and 200° F tests, the impact machine was housed in an insulated cabinet shown in figure 1. The air in the cabinet was circulated by a fan except during the impact tests. Dry ice was used to cool the air; heating was done with electric heaters. The specimens were kept in a conditioning cabinet at the test temperature for about 20 hours and were then placed in the testing cabinet 2 to 4 hours prior to testing.

In testing conducted in the insulated cabinet the operator kept his hands, which were protected with woolen gloves, inside the cabinet for periods of about 15 minutes at a time. This is sufficient for testing about 5 to 10 specimens.

The materials in the 1/2-inch thickness were tested flatwise and edgewise for both the lengthwise and crosswise orientations. Since the Izod-impact machine had a limited capacity (16 ft-lb), the specimens of the glass-filled laminate tested flatwise were made only 0.25 to 0.30 inch wide. Edgewise tests were made on specimens of the 1/8-inch-thick sheets of the materials for both lengthwise and crosswise orientations.

Flexural Properties

The flexural tests were made according to Method 1031 of Federal Specification L-P-406a, using a 2400-pound-capacity Baldwin-Southwark hydraulic universal testing machine which had ranges of 240, 1200, and 2400 pounds. This machine was located in a room in which the atmosphere was controlled at 77° F and 50 percent relative humidity. Tests to obtain flexural strength and load-deflection graphs were made at -70°, 77°, and 200° F. For the low- and high-temperature tests the specimen, the flexural jig, and the deflection indicator were enclosed in a temperature-controlled cabinet equipped with a blower. The arrangement of the flexural apparatus for the low- and high-temperature tests is shown in figures 2 and 3. In figure 2 the insulated cabinet has been removed to show the pressure piece, flexural jig, and attachments.

The flexural jig is initially centered and alined relative to the pressure piece in the following way. The alinement plate (L) having parallel V-grooves is used to locate the flexural jig relative to the pressure piece (F) after the span has been set appropriately. This is done with the contact edge of the pressure piece in the central V-groove in (L) under a light load. The stand is clamped to the magnetic chuck and the latter is energized. As the right- and left-hand sections of the calibrated screw (J) have right- and left-hand threads, respectively, the flexural jig is now self-centering. Subsequent changes in the span merely require loosening the cap screws, setting the screw (J), and tightening the cap screws again.

The deflection of the specimen at the center of the span relative to the supports is indicated by an equal-arm lever (N) actuating a gage shown in figure 3. The gage, a Southwark-Peters plastics extensometer, Type PS-6 or PS-7, is attached to the aluminum alloy brackets (P) which have grooves to locate the knife-edges of the gage. Load-deflection graphs are obtained with this gage coupled to the recorder on the testing machine. The high-magnification gage, Model PS-6, has a range of 0.23 inch and the low-magnification gage, Model PS-7, a range of 1 inch.

In figure 3 the flexural apparatus is shown with a specimen in place and the front of the cabinet removed. Triple-paned windows in the front and side, armholes, and lights inside the cabinet facilitate the manipulation of the specimen and equipment.

Little difficulty was encountered in the high-temperature testing with this equipment. At low temperatures, frost on the electrical contacts of the gage was washed off with ethyl alcohol. Rusting of the flexural jig and gage upon removal from the cabinet was avoided by immersing them in alcohol until they attained room temperature. They were then disassembled and dried thoroughly and the flexural jig re-oiled.

The span of the flexural jig is adjustable from 1.6 to 9 inches and the screw is graduated to 0.002 inch. The combination of recording gage and lever is accurate to about 5 percent in the measurement of deflections over 0.01 inch with the PS-6 gage and to about 3 percent for deflections over 0.1 inch with the PS-7 gage. The percentage error diminishes as the deflection increases. Calibrations were made only at 77° F.

The flexural properties were determined only for the 0.5-inch-thick laminates. Each material was tested four ways, flatwise and edgewise for specimens cut both lengthwise and crosswise. At least five specimens were tested for each material for all orientations. The only deviation from Method 1031 of Federal Specification L-P-406a was the use of a span-depth ratio of 8:1 instead of 16:1 in order to conserve materials. However, for comparative purposes flexure tests were made also at 77° F with a span-depth ratio of 16:1.

RESULTS AND DISCUSSION

Impact Strength

The data for Izod-impact strength of the various laminates at temperatures of -70°, 0°, 77°, and 200° F are presented in table II. The variation in impact strength with temperature is shown graphically in figures 4a and 4b for lengthwise specimens of the 0.5-inch-thick materials tested flatwise. Figures 5 to 8 show the variation of impact strength of paper, cotton-fabric and rayon-cotton-fabric phenolic laminates with temperature for the various orientations of specimen and direction of load.

The Izod-impact strengths at 77° F for the phenolic and glass-fabric laminates tested flatwise are approximately as follows:

Type of Laminate	Izod-Impact Strength (ft-lb/in. of notch)
Grade C phenolic, high-pressure and low-pressure	4 - 7
High-strength-paper phenolic	4
Asbestos-fabric phenolic	2 - 4½
Rayon-cotton-fabric phenolic	17
Glass-fabric unsaturated-polyester	30

The paper and asbestos laminates showed less than 25 percent variation in impact strength over the range of temperature and orientations of specimen and loading investigated.

The variation in impact strength was less than 10 percent for the 0.5-inch-thick paper laminate tested flatwise.

The temperature-impact strength trend for high-strength paper laminate agrees quite well with Shinn's data (reference 7) for flatwise tests where a very slight increase in strength with temperature was found for the range -67° to 158° F. Meyer and Erickson (reference 4) reported that the impact strengths for "Papreg" at the extremes of temperature were slightly less than the normal temperature values, a trend found in this laboratory only for the 0.5-inch sheets tested edgewise. In their impact tests at 158° and 200° F, Meyer and Erickson stated (reference 4) that the specimen was "tested at room temperature within 15 to 30 seconds after removal from the conditioning medium"; this test condition is believed to introduce some uncertainty into the results.

All the cotton-fabric laminates exhibited a steady decrease in impact strength as the temperature was reduced from 77° to -70° F. For materials I2, L2, and V2, the impact strength at -70° F was between 55 and 65 percent of the 77° F value for all orientations of specimen and directions of load employed. The corresponding range for W2, high-pressure grade C laminate, was 73 to 77 percent. Little change in impact strength at 200° F compared to 77° F was observed for the cotton-fabric laminates with the exception of the I2 material. The latter laminate showed a steady increase in impact strength with temperature up to 200° F. These results are in good agreement with values reported for grade-C material by Shinn (reference 7), who found that in flatwise tests impact strengths at -67° and 158° F were 66 and 113 percent, respectively, of the value at 77° F.

Directional properties were observed for the parallel-ply laminates, I2 and K2. The asbestos-fabric material, K2, for which the effect was greatest, exhibited an impact strength in the crosswise direction less than half of the corresponding value in the lengthwise direction.

The rayon and glass-fabric laminates had much higher impact strengths than the other materials and also show different impact-strength versus temperature trends (figs. 4a and 4b). When tested edgewise, the rayon laminate in both the 1/8- and 1/2-inch thicknesses showed a slight but steady decrease in impact strength as the temperature was varied from -70° to 200° F. The glass-fabric laminate, AB2, shows a constant trend toward higher impact strength at low temperatures. This agrees with data on glass-fabric laminates given by both Field (reference 1) and Fuller (reference 6).

The approximate values for the changes in Izod-impact strength at -70° and 200° F are as follows:

Type of laminate	Change in Izod-impact strength -70° F (percent)	Change in Izod-impact strength 200° F (percent)
Grade C phenolic, low-pressure	-40	0 to 5
Grade C phenolic, high-pressure	-25 to -40	+10 to +35
Asbestos-fabric-phenolic	-15	-10
High-strength paper phenolic	0 to -20	+5 to -20
Rayon-fabric phenolic	0 to +35	0 to -10
Glass-fabric unsaturated-polyester	+45	-5 to -15

The impact strength for specimens struck edgewise was lower than that of specimens of the same material tested flatwise. For a given orientation of specimens in the sheet, the ratio of edgewise to the flatwise impact strength was very nearly constant for a given material over the range of temperature employed. These ratios are given in table III for the data in table II. The mean value of this ratio was 0.5 to 0.6 for the cotton-fabric laminates, 0.2 for the paper laminate, 0.8 for the asbestos-fabric laminate, and about 0.4 for the rayon-fabric laminate. The data of Meyer and Erickson (reference 4) for cross-ply high-strength paper laminate give a value of 0.19 for this ratio at the various test temperatures.

In the tests at 200° F the materials may have lost some moisture as compared to those tested at the lower temperatures and may have undergone further cure as a result of the heating. To obtain information relative to these effects, Izod-impact specimens were tested at 77° F after being heated at 200° F for 24 hours and cooled to room temperature for 1 to 2 hours over calcium chloride in a desiccator. The results of these tests are shown in table IV. The low-pressure cotton-fabric materials, L2 and V2, were about 10 percent weaker and the glass-fabric laminate about 10 percent stronger after the 200° F heating. A decrease of 10 percent was noted for the rayon laminate, but this was not significant according to the statistical criterion. (See section on definitions.) No definite effect of the heating on the strength of the other materials was noted.

Flexural Properties

The results of the flexural tests of the laminates at temperatures of -70° to 200° F are shown in table V for an 8:1 span-depth ratio. Values reported include flexural strength, specific flexural strength, initial and secant moduli of elasticity, and specific modulus of elasticity. The percentage changes in strength of the materials from the 77° F values under exposure to the high and low temperatures are also shown in table V. The variations with temperature of flexural strength, specific flexural strength, initial flexural modulus of elasticity, and specific initial flexural modulus of elasticity of the materials are shown in figures 9, 10, 11, and 12, respectively, for the lengthwise-flatwise tests.

A typical load-deflection curve obtained at -70° F with the recorder is shown in figure 13. Average curves of extreme fiber stress versus deflection at midspan are shown in figure 14 for the different materials at 77° F. Similar stress-deflection curves are shown in figures 15 through 23 for the nine laminates at -70°, 77°, and 200° F. Figures 24 and 25 represent the average stress-deflection curves for the four directions of testing at 77° F of the asbestos-fabric laminate and the glass-fabric laminate, U2, respectively. Average stress-deflection curves for specimens taken lengthwise, crosswise, and on the diagonal from the rayon laminate, Z2, and the glass laminate, AB2, are shown in figures 26 and 27, respectively. The experimental stress-deflection data were adjusted for the thickness of the material by multiplying the measured deflection at midspan by the ratio of standard thickness to the actual thickness; the curves shown in figures 14 through 27 were calculated for a standard thickness of 0.50 inch.

The flatwise flexural properties of some of the laminates at 77° F were approximately as follows:

Type of laminate	Flexural strength (10^3 psi)	Initial flexural modulus of elasticity (10^6 psi)
Grade C phenolic, low-pressure	16	0.80
Grade C phenolic, high-pressure	18 to 22	1.0 to 1.1
Asbestos-fabric phenolic	9(C) and 16(L)	1.0(C) and 1.2(L)
High-strength-paper phenolic	33	2.4
Rayon-cotton-fabric phenolic	34	1.6
Glass-fabric unsaturated-polyester	45(C) and 55(L)	2.5 to 2.9

(C) - Crosswise (L) - Lengthwise

The four cotton-fabric phenolic laminates, I2, L2, V2, and W2, exhibit quite similar properties. For a given material the properties were generally equal to within 15 percent for the various orientations of specimen and load. The flexural strength of these cotton-fabric laminates increased about 10 to 30 percent at -70° F and decreased very nearly 30 percent at 200° F, compared to the 77° F values. Corresponding changes for the initial modulus of elasticity were increases of 40 to 80 percent at -70°F and moderate decreases up to about 25 percent at 200° F. The variations of secant modulus values with temperature are greater than for the initial modulus of elasticity.

These results are in fair agreement with data for grade C phenolic laminate given by Oberg, Schwartz, and Shinn (reference 2). They observed increases in flexural strength and flexural modulus of elasticity of about 17 percent at -38° F compared to values at 78° F and 40 percent relative humidity.

The asbestos-fabric laminate, K2, of parallel-ply construction showed directional effects, especially in regard to the flexural strength. (See table V.) The variation of the strength properties of this material with temperature was less than that of the cotton-fabric laminates and the trend is different. Most of the change in flexural properties of the asbestos-fabric laminate occurred between 77° and -70° F; the flexural strength and initial modulus of elasticity increased roughly 20 and 35 percent, respectively, at -70° F. The average change in flexural properties at 200° F was not over 5 percent. The stress-deflection curves for this material (fig. 16) indicate the similarity between the properties at 77° and 200° F.

The flexural strength and initial flexural modulus of elasticity of the paper phenolic laminate, S2, varied with temperature in a manner similar to the values for the cotton-fabric laminates except that the initial modulus of elasticity increased only 20 percent between 77° and -70° F.

Meyer and Erickson (reference 4) reported that the flexural strength and flexural modulus of elasticity for high-strength-paper phenolic laminate decreased at elevated temperatures and increased at subnormal temperatures. The magnitudes of the changes which they recorded agree fairly well with the data given in this report. Their material was quite similar to that tested at this laboratory, being made with the same resin under approximately the same molding conditions and with a similar type of paper. In tests at the Naval Air Experimental Station (reference 5) on a phenolic material laminated with a spruce sulfite paper, probably of the high-strength type, it was noted that the flexural strength and flexural modulus of elasticity at 160° F were about a third less than at 77° F. From a comparison of the data obtained by various investigators it is concluded that, while the flexure-property temperature trend is definite, the magnitudes of the changes must be determined on each sample.

The two glass-fabric laminates, U2 and AB2, showed the same trend in change of flexural strength and modulus of elasticity with temperature (figs. 9 and 11). The flexural strength increased about one-third at -70° F and decreased about one-third at 200° F. The flexural strengths of the two materials did not differ significantly. The AB2 laminate was superior to the U2 material in flexural modulus of elasticity, having greater values at all temperatures and for all directions of testing. The percentage decrease in modulus of elasticity at 200° F was less for the AB2 than for the U2 laminate.

For both glass-fabric laminates the stress-deflection diagrams were less curved than for any other materials tested. In the lengthwise and crosswise directions the secant modulus of elasticity for the range 0 to 25,000 psi showed a decrease of less than 10 percent from the initial modulus of elasticity at all the temperatures.

The approximate values for the changes in flexural strength and flexural modulus of elasticity at -70° and 200° F for the lengthwise and crosswise directions of the laminates investigated may be summarized as follows:

Type of laminate	Change in flexural strength		Change in initial flexural modulus of elasticity	
	-70° F (percent)	200° F (percent)	-70° F (percent)	200° F (percent)
Grade C phenolic	10 to 30	-30	40 to 80	-8 to -25
Asbestos-fabric phenolic	20	-5	35	0
High-strength-paper phenolic	25	-40	20	-18
Rayon-cotton-fabric phenolic	30	-25	40	-30
Glass-fabric unsaturated-polyester	30	-30 to -35	10 to 15	15 to -25

Four of the nine materials tested, the two glass-fabric laminates, the asbestos-fabric laminate, and the grade C laminate, I2, were of parallel-ply construction. The most pronounced difference in strength properties between specimens taken from the principal directions of the sheet was observed in the asbestos-fabric laminate, K2. Its crosswise impact and flexural strengths were only half of those for the lengthwise direction. The lengthwise flexural properties of the two glass-fabric laminates differ less than 15 percent from the corresponding crosswise flexural properties. The differences between the flexural properties for the lengthwise and crosswise directions for the grade C parallel-ply laminate, I2, were small and were of the same order of magnitude as the corresponding difference for the three cross-ply cotton-fabric laminates. The flexural properties of the AB2 glass-fabric and of the rayon-fabric laminate are greatly reduced for the 45° direction. The flexural strength and initial flexural modulus of elasticity values for the 45° direction for the glass-fabric laminate are two-thirds and for the rayon-fabric laminate are one-half of the average values for the two principal directions.

When the density is considered in evaluating the flexural properties of the materials, the cellulose-filled laminates, with lower densities than the mineral-filled laminates, compare more favorably with the latter materials and are superior in some instances. This may be seen by comparing figures 9 and 10 or 11 and 12. The specific flexural strength values are in the ratios of 18:17:16 for the rayon-fabric, paper, and glass-fabric laminates, respectively. The specific initial flexural modulus of elasticity values are in the ratios of 9:6:5 for the paper, rayon-fabric, and glass-fabric laminates. These graphs also show that there is no difference in specific strength properties between the low-pressure and high-pressure laminates, V2 and W2, made with the same grade C fabric.

Flexural tests were also made at 77° F on specimens heated at 200° F for 24 hours to determine whether changes in the strength properties occurred in the 200° F tests. Such changes may be brought about by (a) additional cure of the resin, (b) loss of moisture, (c) deterioration of the filler if organic, or (d) a combination of these factors. The results of these tests and of tests on unheated specimens are shown in table VI. The flexural strength values showed an average decrease of about 8 to 13 percent for the cotton-fabric and paper laminates. The changes in the flexural moduli of elasticity were small and not consistent except for the low-pressure material, L2, which exhibited increases of 10 percent after heating. The glass-fabric laminate, U2, exhibited average increases of 11 and 4 percent, respectively, in flexural strength and moduli of elasticity on heating. The asbestos-fabric laminate, K2, also exhibited higher flexural properties after heating, the increases in flexural strength and moduli of elasticity being about 7 and 12 percent, respectively.

It seems reasonable that the strength and modulus of elasticity values of these organic plastics should diminish with increase in temperature if no change in composition or structure takes place. If heating a laminate at 200° F for 24 hours causes an increase in the strength properties due to a change in composition or structure, then in the flexural tests at 200° F (table V) the effects of prolonged heating and of an elevated test temperature may oppose one another. This may explain the very small differences between the flexure properties at 77° and 200° F (table V) for the asbestos-fabric laminate which had increased flexural properties at 77° F after heating (table VI). The effect of prolonged heating on the flexural strength of laminates was investigated by Hausmann, Parkinson, and Mains (reference 9). They found that the flexural strength of grades C, X, and XXX phenolic laminates at 90° C increased with the length of time the specimens were at the test temperature. (See table I, reference 9.) For the grade XXX laminate the flexural strength values at 90° C after a month of heating were nearly equal to the 25° C values on unheated specimens.

Flexural strength tests were made on six laminates at 150° F and 90 percent relative humidity after 24 hours conditioning at the test temperature, combining the effects of elevated temperature and high relative humidity. The results of these tests are given in table VIII together with corresponding data from table V for the 77° and 200° F tests.

The deleterious effect of these extreme conditions was most pronounced for the paper laminate, S2, and the low-pressure grade C laminate, V2. The other four materials were not so greatly affected by these conditions as they were by 24 hours at 200° F and a low relative humidity. The effect of moisture content on the strength properties of high-strength-paper laminate was studied by Erickson and Mackin (reference 10). They tested specimens from a series of panels conditioned 100 days at 80° F at various relative humidities. They found decreases in ultimate strength in tension, compression, and flexure of 25 percent or more and decreases of about 35 percent in modulus of elasticity as the relative humidity was varied from 30 percent to 97 percent, corresponding to moisture contents ranging from 0.2 to 9.5 percent.

The above results and the results obtained in this laboratory indicate the necessity for studying the effect of relative humidity as well as temperature on the strength properties of laminates, especially those with cellulosic fillers.

The results of tests made at 77° F using span-depth ratios of 16:1 and 8:1 are given in table VII. The flexural strength obtained with a 16:1 span-depth ratio was slightly less for all materials, the decreases ranging from about 2 percent for the glass-fabric laminate, U2, to about 7 percent for the cotton-fabric phenolic laminates. The initial flexural modulus of elasticity values were usually a little greater for the tests with the larger span-depth ratio. The I2 material, a high-pressure phenolic grade C laminate, showed significant changes in both flexural strength and initial modulus of elasticity with the change in span-depth ratio. Significant changes in only one of the two properties occurred for the rest of the materials listed in table VII.

CONCLUSIONS

1. The Izod-impact strength-temperature trend of the laminated plastics is different for the various types of material. The glass-fabric laminates decreased steadily in impact strength with increasing temperature, the value at 200° F being about 70 percent of the -70° value. The asbestos-fabric, rayon-fabric, and high-strength-paper phenolics showed little variation in impact strength between -70° and 200° F. The cotton-fabric phenolics exhibited increasing impact strength with temperature, roughly doubling their impact strength between -70° and 200° F.

2. The Izod-impact strength values for the rayon-fabric and the glass-fabric laminates are much greater than for the other materials.

3. The ratio of edgewise to flatwise impact strength for the 1/2-inch-thick phenolic laminates tested is nearly constant over the range of temperatures, -70° to 200° F.

4. An increase in flexural properties occurred for all materials at low temperature, and at high temperature a decrease occurred for all materials except the asbestos-fabric laminate, which showed no change.

5. The high-strength-paper and two glass-fabric laminates are outstanding in flexural properties. When the materials are compared on the basis of specific strength values, the paper and rayon-fabric laminates are superior to the others.

6. The low-pressure grade-C phenolic laminate, V2, compared favorably in flexural strength properties with the high-pressure laminate made with the same filler, especially when the comparison was made in terms of specific strength properties.

7. The flexural properties of plastic laminates at high temperature are not a function of temperature alone, but may

be affected by further cure of the resin and loss of moisture content.

8. The effect of high humidity in addition to an elevated temperature may be much different from the effect of the elevated temperature alone. A severe loss in strength was noted for the high-strength-paper and one low-pressure cotton-fabric phenolic laminate at 150° F and 90 percent relative humidity.

National Bureau of Standards,
Washington, D. C., December 29, 1945.

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TABLE I.- DESCRIPTION OF MATERIALS

NBS Designation	Type of Laminate	Density (gm/cm^3)	Thickness, Average (in.)	Manufacturer	Resin		Reinforcement					Molding Conditions			
					Type	Content by Weight (%)	Type	Thread Count Warp	Thread Count Filling	No. of Plies	Ply Arrangement	Pressure (lb/in^2)	Temperature (°F)	Time of Heating (min.)	Time of Cooling (min.)
I2	Grade C Phenolic	1.34	0.53	Synthane Corp.	Bakelite BV-1112	48	Cotton Fabric	50	40	27	Parallel	1,800	340 ± 20	50	50
R2	Asbestos-Fabric Phenolic	1.48	0.57	Synthane Corp.	Bakelite 2427	47	Asbestos Fabric	18	16	20	Parallel	1,800	340 ± 20	50	50
L2	Low-Pressure Cotton-Fabric Phenolic	1.32	0.60	Bakelite Corp.	Bakelite BV-16887	52	Enameled Duck 8 oz/yd^2	84	28	35	Cross	250	325	30	
S1 S2	High-Strength-Paper Phenolic	1.42 1.42	0.12 0.50	Consolidated Water Power and Paper Co.	Bakelite 16526	30	High-strength Mitscherlich Paper			27 per .060 in. Thickness	Cross	250	310 ± 10		
U2	Glass-Fabric Unsaturated Polyester	1.78	0.60	Plaskon Div., Libbey-Owens-Ford Glass Co.	Plaskon 900	50	Glass Fabric, ECC-11-162			160	Parallel	50	122 230	720 240	none
V1 V2	Low-Pressure Grade C Phenolic	1.27 1.29	0.15 0.55	Synthane Corp.	Bakelite BV-16887	51	Army Duck, 10.38 oz/yd^2			7 26[a]	Cross	180	320	50	
W1 W2	High-Pressure Grade C Phenolic	1.36 1.36	0.14 0.45	Synthane Corp.	Bakelite BV-1112	47	Army Duck, 10.38 oz/yd^2			7 29	Cross	1,800	320	50	
Z1 Z2	Rayon-Cotton-Fabric Phenolic	1.37 1.37	0.16 0.48	Formica Insulation Co.	Ironsides Co. Phenolic 91-L	37-40	Fortisan	75 Rayon	12 Cotton	7 23	Cross	1,100	310 ± 10	20	20
AB1	Glass-Fabric Unsaturated-Polyester	1.82	0.13	Army Air Forces Technical Service Command	Plaskon 900	43	Fiberglas ECC-11-112			42	Parallel	40	180 220	120 120	
AB2	do.	1.86	0.49	do.	do.		do.			166	do.	40	160 180 200 220	120 120 120 120	

a. Warp directions at right angles in the two face plies.

TABLE II.- IZOD-IMPACT STRENGTHS OF LAMINATED PLASTICS AT VARIOUS TEMPERATURES[a]

	Orientation of Specimen	Direction of Load	Tests at -70° F Impact Strength[b] (ft-lb/in. of notch)	Tests at -70° F Range of Machine (ft-lb)	Tests at 0° F Impact Strength[b] (ft-lb/in. of notch)	Tests at 0° F Range of Machine (ft-lb)	Tests at 77° F Impact Strength[b] (ft-lb/in. of notch)	Tests at 77° F Range of Machine (ft-lb)	Tests at 200° F Impact Strength[b] (ft-lb/in. of notch)	Tests at 200° F Range of Machine (ft-lb)
					One-Half-Inch Thick Material					
I2, Grade C Phenolic	Lengthwise	Flatwise	2.81 ± 0.07	8	3.89 ± 0.10	8	5.06 ± 0.14	8	6.69 ± 0.07	8
	Crosswise	Flatwise	2.45 ± 0.06	8	3.13 ± 0.05	8	4.03 ± 0.05	8	5.25 ± 0.13	8
	Lengthwise	Edgewise	1.74 ± 0.02	8	2.26 ± 0.02	8	2.69 ± 0.03	2	3.85 ± 0.04	8
	Crosswise	Edgewise	1.46 ± 0.01	8	1.91 ± 0.02	8	2.34 ± 0.03	2	3.19 ± 0.04	8
K2, Asbestos-Fabric Phenolic	Lengthwise	Flatwise	4.13 ± 0.09	8	4.26 ± 0.04	8	4.58 ± 0.07	8	4.22 ± 0.08	8
	Crosswise	Flatwise	1.63 ± 0.06	2	1.99 ± 0.05	8	2.01 ± 0.14	2	1.75 ± 0.07	8
	Lengthwise	Edgewise	3.19 ± 0.08	8	3.40 ± 0.06	8	3.84 ± 0.03	8	3.46 ± 0.03	8
	Crosswise	Edgewise	1.33 ± 0.05	8	1.46 ± 0.02	8	1.60 ± 0.05	8	1.50 ± 0.04	8
L2, Low-Pressure Cotton-Fabric Phenolic	Lengthwise	Flatwise	3.30 ± 0.04	8	4.17 ± 0.06	8	5.98 ± 0.08	8	6.09 ± 0.05	8
	Crosswise	Flatwise	3.32 ± 0.05	8	4.18 ± 0.06	8	5.96 ± 0.06	8	5.82 ± 0.07	8
	Lengthwise	Edgewise	1.87 ± 0.02	8	2.32 ± 0.02	8	3.22 ± 0.03	8	3.28 ± 0.02	8
	Crosswise	Edgewise	1.85 ± 0.03	8	2.39 ± 0.02	8	3.09 ± 0.01	8	3.22 ± 0.05	8
S2, High Strength-Paper Phenolic	Lengthwise	Flatwise	4.07 ± 0.08	8	4.21 ± 0.09	8	4.18 ± 0.10	8	4.36 ± 0.24	8
	Crosswise	Flatwise	4.21 ± 0.11	8	4.18 ± 0.11	8	4.17 ± 0.14	8	4.53 ± 0.17	8
	Lengthwise	Edgewise	0.694 ± 0.005	2	0.726 ± 0.008	2	0.841 ± 0.012	2	0.688 ± 0.009	2
	Crosswise	Edgewise	0.709 ± 0.007	2	0.741 ± 0.010	2	0.867 ± 0.008	2	0.686 ± 0.005	2
V2, Low-Pressure Grade C Phenolic	Lengthwise	Flatwise	3.93 ± 0.07	8	5.40 ± 0.19	8	6.57 ± 0.14	8	6.64 ± 0.14	8
	Crosswise	Flatwise	3.79 ± 0.14	8	5.04 ± 0.11	8	6.26 ± 0.13	8	6.39 ± 0.20	8
	Lengthwise	Edgewise			2.51 ± 0.05	2	3.30 ± 0.08	8	3.35 ± 0.11	8
	Crosswise	Edgewise			2.59 ± 0.06	2	3.31 ± 0.06	8	3.57 ± 0.06	8
W2, High-Pressure Grade C Phenolic	Lengthwise	Flatwise	4.15 ± 0.07	8	5.12 ± 0.25	8	5.69 ± 0.29	8	5.80 ± 0.28	8
	Crosswise	Flatwise	3.87 ± 0.08	8	4.34 ± 0.15	8	5.27 ± 0.37	8	6.46 ± 0.60	8
	Lengthwise	Edgewise	2.12 ± 0.05	8	2.40 ± 0.11	2	2.75 ± 0.14	2	3.02 ± 0.14	8
	Crosswise	Edgewise	2.42 ± 0.02	8	2.46 ± 0.11	2	3.22 ± 0.17	8	3.87 ± 0.26	8
Z2, Rayon-Cotton-Fabric Phenolic	Lengthwise	Flatwise	17.0 ± 0.6	16	18.4 ± 0.6	16	17.6 ± 0.6	16	15.8 ± 0.4	16
	Crosswise	Flatwise	18.6 ± 0.9	16	19.1 ± 0.6	16	17.4 ± 0.7	16	16.4 ± 0.6	16
	Lengthwise	Edgewise	9.02 ± 0.32	8	7.96 ± 0.10	8	6.62 ± 0.09	8	5.94 ± 0.35	8
	Crosswise	Edgewise	7.70 ± 0.15	8	6.94 ± 0.21	8	5.91 ± 0.15	8	5.00 ± 0.28	8
AB2, Glass-Fabric Unsaturated-Polyester	Lengthwise	Flatwise	46.1 ± 0.7	16	39.8 ± 0.9	16	31.5 ± 0.6	16	26.6 ± 0.5	16
	Crosswise	Flatwise					29.4 ± 0.8	16		
	Lengthwise	Edgewise					9.88 ± 0.05	16		
	Crosswise	Edgewise					9.03 ± 0.03	16		
					One-Eighth-Inch Thick Material[c]					
S1, High-Strength-Paper Phenolic	Lengthwise	Edgewise	0.612 ± 0.006	2	0.608 ± 0.005	2	0.640 ± 0.008	2	0.664 ± 0.007	2
	Crosswise	Edgewise	0.622 ± 0.004	2	0.638 ± 0.007	2	0.629 ± 0.015	2	0.623 ± 0.004	2
V1, Low-Pressure Grade C Phenolic	Lengthwise	Edgewise	1.94 ± 0.02	2	2.46 ± 0.02	2	3.23 ± 0.06	2	3.15 ± 0.05	2
	Crosswise	Edgewise	1.86 ± 0.03	2	2.39 ± 0.02	2	2.94 ± 0.04	2	3.11 ± 0.05	2
W1, High-Pressure Grade C Phenolic	Lengthwise	Edgewise	1.84 ± 0.04	2	2.21 ± 0.05	2	2.72 ± 0.05	2	3.13 ± 0.09	2
	Crosswise	Edgewise	1.67 ± 0.03	2	2.16 ± 0.05	2	2.71 ± 0.03	2	2.96 ± 0.04	2
Z1, Rayon-Cotton-Fabric Phenolic	Lengthwise	Edgewise	12.9 ± 0.3	8	13.0 ± 0.6	8	11.8 ± 0.2	8	12.2 ± 0.3	8
	Crosswise	Edgewise	8.74 ± 0.17	8	7.82 ± 0.14	8	7.13 ± 0.09	8	6.91 ± 0.16	8
AB1, Glass-Fabric Unsaturated-Polyester	Lengthwise	Edgewise	14.4 ± 0.2	2	12.0 ± 0.4	2	10.0 ± 0.3	2	9.58 ± 0.16	2
	Crosswise	Edgewise					10.9 ± 0.2	2		

a. The tests were made in accordance with Method 1071, Federal Specification L-P-406a.

b. Mean value for nine to twelve specimens for all materials except glass-fabric laminate AB2, for which twenty to twenty-five specimens were tested.

c. The specimens were tested individually in the one-eighth inch thickness; composite specimens were not used.

Table III.- Ratio of Edgewise Impact Strength to Flatwise Impact Strength for Laminated Plastics at Various Temperatures.

Material Designation	Orientation of Specimen	Ratio at Test Temperature of				Mean Ratio, All Temp.
		-70° F	0° F	77° F	200° F	
I2, Grade C Phenolic	Lengthwise Crosswise	0.62 0.60	0.58 0.61	0.53 0.58	0.58 0.61	0.59
K2, Asbestos-Fabric Phenolic	Lengthwise Crosswise	0.77 0.82	0.80 0.73	0.84 0.80	0.82 0.85	0.80
L2, Low-Pressure Cotton-Fabric Phenolic	Lengthwise Crosswise	0.57 0.56	0.56 0.58	0.54 0.52	0.54 0.55	0.55
S2, High-Strength-Paper Phenolic	Lengthwise Crosswise	0.17 0.17	0.17 0.18	0.20 0.21	0.16 0.15	0.18
V2, Low-Pressure Grade C Phenolic	Lengthwise Crosswise		0.46 0.51	0.50 0.53	0.50 0.56	0.51
W2, High-Pressure Grade C Phenolic	Lengthwise Crosswise	0.51 0.63	0.47 0.57	0.48 0.61	0.52 0.60	0.55
Z2, Rayon-Cotton-Fabric Phenolic	Lengthwise Crosswise	0.53 0.41	0.43 0.36	0.38 0.34	0.38 0.30	0.39
AB2, Glass-Fabric Unsaturated-Polyester	Lengthwise Crosswise			0.32 0.32		

TABLE IV.- EFFECT OF HEATING AT 200°F FOR 24 HOURS ON IZOD-IMPACT STRENGTHS OF LAMINATED PLASTICS[a]

Material Designation	Orientation of Specimen	Direction of Load	Impact Strength[b]: No Heating[c] (ft-lb/in. of notch)	Range of Machine (ft-lb)	Heated at 200°F[d] (ft-lb/in. of notch)	Range of Machine (ft-lb)
I2, Grade C Phenolic	Lengthwise	Flatwise	5.06 ± 0.14	8	5.13 ± 0.13	8
	Crosswise	Flatwise	4.03 ± 0.05	8	4.21 ± 0.07	8
K2, Asbestos-Fabric Phenolic	Lengthwise	Edgewise	3.84 ± 0.03	8	3.86 ± 0.06	8
	Crosswise	Edgewise	1.60 ± 0.05	8	1.48 ± 0.03	2
L2, Low-Pressure Cotton-Fabric Phenolic	Lengthwise	Edgewise	3.22 ± 0.03	8	2.88 ± 0.04	8
	Crosswise	Edgewise	3.09 ± 0.01	8	2.85 ± 0.02	8
S2, High-Strength-Paper Phenolic	Lengthwise	Flatwise	4.18 ± 0.10	8	4.02 ± 0.18	8
	Crosswise	Flatwise	4.17 ± 0.14	8	4.29 ± 0.20	8
V2, Low-Pressure Grade C Phenolic	Lengthwise	Flatwise	6.57 ± 0.14	8	5.95 ± 0.21	8
	Crosswise	Flatwise	6.26 ± 0.13	8	5.55 ± 0.10	8
W2, High-Pressure Grade C Phenolic	Crosswise	Flatwise	5.27 ± 0.37	8	4.93 ± 0.12	8
Z2, Rayon-Cotton-Fabric Phenolic	Lengthwise	Flatwise	17.6 ± 0.6	16	16.0 ± 0.4	16
	Crosswise	Flatwise	17.4 ± 0.7	16	15.8 ± 1.0	16
AB2, Glass-Fabric Unsaturated-Polyester	Lengthwise	Flatwise	31.5 ± 0.6	16	35.5 ± 0.8	16

a. The tests were made in accordance with Method 1071, Federal Specification L-P-406a.

b. Mean value for nine to twelve specimens for all materials except glass-fabric laminate AB2, for which 20 to 25 specimens were tested. The accompanying plus or minus value is the standard error.

c. Specimens conditioned and tested at 77°F and 50% relative humidity.

d. Specimens tested at 77°F after being allowed to cool to room temperature for 1 to 2 hours in a desiccator containing calcium chloride.

TABLE V.- FLEXURAL PROPERTIES OF LAMINATED PLASTICS AT VARIOUS TEMPERATURES[a]

Material Designation	Orientation of Specimen	Direction of Load	Temp. Test (°F)	Flexural Strength, S_f: Mean[b] (10^3 lb/in²)	Flexural Strength, S_f: Change[c] (%)	Flexural Modulus of Elasticity: Initial Value, E_i: Mean[b] (10^6 lb/in²)	Flexural Modulus of Elasticity: Initial Value, E_i: Change[c] (%)	Mean Secant Modulus for Various Ranges of Stress[b] (10^6 lb/in²)	Mean Secant Modulus for Various Ranges of Stress[b] (10^6 lb/in²)	Mean Secant Modulus for Various Ranges of Stress[b] (10^6 lb/in²)	Specific Strength Values: $S_f/(\text{Sp.Gr.})^2$ (10^3 lb/in²)	Specific Strength Values: $E_i/(\text{Sp.Gr.})^3$ (10^6 lb/in²)
								0-5,000 lb/in²	0-10,000 lb/in²	0-15,000 lb/in²		
I2, Grade C Phenolic	Lengthwise	Flatwise	-70	24.8 ± 0.7	+12	1.60 ± 0.02	+48		1.52 ± 0.01	1.41 ± 0.02	13.8	0.665
			77	22.2 ± 0.3		1.08 ± 0.02		1.08 ± 0.02	1.07 ± 0.02		12.4	0.449
			200	14.5 ± 0.1	-35	0.86 ± 0.03	-20	0.83 ± 0.02	0.65 ± 0.01		8.1	0.357
	Crosswise	Flatwise	-70	23.6 ± 0.5	+14	1.47 ± 0.03	+37		1.43 ± 0.06	1.31 ± 0.06	13.1	0.611
			77	20.7 ± 0.3		1.07 ± 0.07		1.07 ± 0.07	1.02 ± 0.04		11.5	0.445
			200	13.5 ± 0.1	-35	0.83 ± 0.03	-22	0.80 ± 0.04	0.63 ± 0.02		7.5	0.345
	Lengthwise	Edgewise	-70	25.0 ± 0.4	+18	1.70 ± 0.03	+49		1.59 ± 0.01	1.48 ± 0.02	13.9	0.706
			77	21.2 ± 0.2		1.14 ± 0.03		1.14 ± 0.03	1.09 ± 0.02		11.8	0.474
			200	14.6 ± 0.1	-31	0.89 ± 0.01	-22	0.89 ± 0.01	0.69 ± 0.01		8.1	0.370
	Crosswise	Edgewise	-70	23.6 ± 0.3	+10	1.53 ± 0.05	+38		1.49 ± 0.04	1.40 ± 0.04	13.1	0.636
			77	21.4 ± 0.4		1.11 ± 0.08		1.11 ± 0.08	1.04 ± 0.07		11.9	0.461
			200	13.8 ± 0.2	-36	0.88 ± 0.01	-21	0.88 ± 0.01	0.69 ± 0.01		7.7	0.366
								0-5,000 lb/in²	0-7,500 lb/in²	0-10,000 lb/in²		
K2, Asbestos-Fabric Phenolic	Lengthwise	Flatwise	-70	20.4 ± 1.1	+25	1.64 ± 0.03	+37	1.62 ± 0.03		1.56 ± 0.03	9.3	0.506
			77	16.3 ± 0.6		1.20 ± 0.02		1.20 ± 0.02		1.13 ± 0.02	7.4	0.370
			200	15.8 ± 0.3	-3	1.22 ± 0.01	+ 2	1.22 ± 0.01		1.16 ± 0.01	7.2	0.376
	Crosswise	Flatwise	-70	11.8 ± 0.2	+33	1.33 ± 0.02	+34	1.31 ± 0.01	1.28 ± 0.01		5.4	0.410
			77	8.9 ± 0.2		0.99 ± 0.01		0.99 ± 0.01	0.92 ± 0.01		4.1	0.305
			200	8.3 ± 0.3	-7	0.95 ± 0.01	- 4	0.95 ± 0.01			3.8	0.293
	Lengthwise	Edgewise	-70	20.4 ± 0.3	+24	1.66 ± 0.06	+44	1.66 ± 0.06		1.56 ± 0.03	9.3	0.512
			77	16.4 ± 0.2		1.15 ± 0.02		1.15 ± 0.02		1.05 ± 0.01	7.5	0.355
			200	15.3 ± 0.5	-7	1.21 ± 0.01	+ 5	1.21 ± 0.01		1.16 ± 0.02	7.0	0.373
	Crosswise	Edgewise	-70	10.4 ± 0.3	+11	1.35 ± 0.05	+39	1.31 ± 0.04	1.88 ± 0.03		4.7	0.416
			77	9.4 ± 0.1		0.97 ± 0.02		0.97 ± 0.02	0.90 ± 0.02		4.3	0.299
			200	9.1 ± 0.1	-3	0.94 ± 0.02	- 3	0.94 ± 0.02	0.90 ± 0.02		4.2	0.290
								0-5,000 lb/in²	0-10,000 lb/in²			
L2, Low-Pressure Cotton-Fabric Phenolic	Lengthwise	Flatwise	-70	22.4 ± 0.2	+22	1.37 ± 0.02	+71	1.31 ± 0.01	1.23 ± 0.01		12.9	0.596
			77	18.4 ± 0.2		0.80 ± 0.01		0.80 ± 0.01	0.67 ± 0.01		10.6	0.348
			200	12.9 ± 0.1	-30	0.75 ± 0.01	- 6	0.71 ± 0.01	0.48 ± 0.01		7.4	0.326
	Crosswise	Flatwise	-70	22.1 ± 0.4	+22	1.32 ± 0.01	+65	1.29 ± 0.01	1.21 ± 0.01		12.7	0.574
			77	18.1 ± 0.2		0.80 ± 0.01		0.80 ± 0.01	0.67 ± 0.01		10.4	0.348
			200	12.8 ± 0.1	-29	0.78 ± 0.04	- 2	0.70 ± 0.02	0.47 ± 0.01		7.3	0.339
	Lengthwise	Edgewise	-70	21.7 ± 0.1	+24	1.30 ± 0.01	+67	1.27 ± 0.01	1.21 ± 0.01		12.5	0.565
			77	17.5 ± 0.2		0.78 ± 0.01		0.78 ± 0.01	0.65 ± 0.01		10.0	0.339
			200	12.4 ± 0.1	-29	0.69 ± 0.01	-12	0.68 ± 0.01	0.46 ± 0.01		7.1	0.300
	Crosswise	Edgewise	-70	21.2 ± 0.3	+21	1.35 ± 0.01	+78	1.32 ± 0.01	1.26 ± 0.01		12.2	0.587
			77	17.5 ± 0.4		0.76 ± 0.02		0.76 ± 0.02	0.64 ± 0.01		10.0	0.330
			200	12.6 ± 0.1	-28	0.70 ± 0.01	- 8	0.69 ± 0.01	0.47 ± 0.01		7.2	0.304

Table V, Continued

Material Designation	Orientation of Specimen	Direction of Load	Temp. Test (°F)	Flexural Strength, S_F: Mean[b] (10^3 lb/in²)	Flexural Strength, S_F: Change[c] (%)	Flexural Modulus of Elasticity — Initial Value, E_i: Mean[b] (10^6 lb/in²)	Flexural Modulus of Elasticity — Initial Value, E_i: Change[c] (%)	Mean Secant Modulus for Various Ranges of Stress[b]: 0-10,000 lb/in² (10^6 lb/in²)	0-15,000 lb/in² (10^6 lb/in²)	0-20,000 lb/in² (10^6 lb/in²)	0-25,000 lb/in² (10^6 lb/in²)	Specific Strength Values: $S_F/(\text{Sp.Gr})^2$ (10^3 lb/in²)	Specific Strength Values: $E_i/(\text{Sp.Gr.})^3$ (10^6 lb/in²)
E2, Rayon-Cotton-Fabric Phenolic	Lengthwise	Flatwise	-70	43.7 ± 0.4	+27	2.34 ± 0.05	+46			2.13 ± 0.02	2.05 ± 0.02	23.2	0.910
			77	34.4 ± 0.5		1.58 ± 0.02			1.42 ± 0.03	1.83 ± 0.04		18.3	0.614
			200	25.8 ± 0.2	-25	1.16 ± 0.03	-27	1.00 ± 0.02	0.82 ± 0.02	0.70 ± 0.02		13.7	0.451
	Crosswise	Flatwise	-70	41.2 ± 0.2	+26	1.88 ± 0.01	+34			1.71 ± 0.01	1.63 ± 0.01	21.9	0.731
			77	32.7 ± 0.5		1.40 ± 0.01			1.25 ± 0.02	1.09 ± 0.02		17.4	0.544
			200	23.7 ± 0.6	-28	0.87 ± 0.05	-38	0.71 ± 0.05	0.60 ± 0.03	0.55 ± 0.02		12.6	0.338
	45° Diagonal	Flatwise	77	18.9 ± 0.1		0.76 ± 0.01		0.70 ± 0.01	0.56 ± 0.01			10.0	0.296
	Lengthwise	Edgewise	-70	43.4 ± 0.3	+30	2.16 ± 0.04	+38			2.01 ± 0.02	1.92 ± 0.02	23.1	0.840
			77	33.4 ± 0.5		1.57 ± 0.03			1.43 0.03	1.85 ± 0.03		17.8	0.610
			200	24.6 ± 0.2	-26	1.13 ± 0.02	-28	0.94 ± 0.02	0.76 ± 0.01	0.67 ± 0.01		13.1	0.439
	Crosswise	Edgewise	-70	41.4 ± 0.3	+31	2.14 ± 0.02	+43			1.92 ± 0.01	1.85 ± 0.01	22.0	0.832
			77	31.7 ± 0.2		1.50 ± 0.01			1.37 ± 0.01	1.20 ± 0.01		16.9	0.583
			200	23.6 ± 0.4	-26	1.12 ± 0.03	-25	0.96 ± 0.04	0.77 ± 0.03	0.66 ± 0.02		12.6	0.435
	45° Diagonal	Edgewise	77	18.3 ± 0.1		0.74 ± 0.01		0.69 ± 0.01	0.54 ± 0.01			9.7	0.288
ABS, Glass-Fabric Unsaturated-Polyester	Lengthwise	Flatwise	-70	70.5 ± 1.3	+32	3.15 ± 0.06	+ 9			3.08 ± 0.03	3.04 ± 0.03	20.4	0.490
			77	53.2 ± 0.1		2.88 ± 0.01				2.80 ± 0.02	2.77 ± 0.02	15.4	0.448
			200	33.0 ± 0.8	-38	2.48 ± 0.02	-14	2.36 ± 0.04	2.31 ± 0.04	2.36 ± 0.04	2.21 ± 0.04	9.5	0.386
	Crosswise	Flatwise	77	46.0 ± 0.7		2.64 ± 0.03				2.61 ± 0.01	2.57 ± 0.01	13.3	0.442
	45° Diagonal	Flatwise	77	35.7 ± 0.4		1.81 ± 0.02		1.63 ± 0.01	1.39 ± 0.01	1.18 ± 0.01		10.3	0.281
	Lengthwise	Edgewise	-70	81.8 ± 0.7	+34	3.40 ± 0.08	+18			3.24 ± 0.04	3.20 ± 0.03	23.6	0.528
			77	60.8 ± 0.5		2.89 ± 0.02				2.87 ± 0.01	2.85 ± 0.01	17.6	0.449
			200	41.4 ± 1.2	-32	2.53 ± 0.04	-12	2.50 ± 0.04	2.50 ± 0.04	2.48 ± 0.04	2.45 ± 0.04	12.0	0.393
	Crosswise	Edgewise	77	53.5 ± 0.7		2.62 ± 0.02				2.66 ± 0.01	2.61 ± 0.02	15.5	0.438
	45° Diagonal	Edgewise	77	37.6 ± 0.5		1.85 ± 0.05		1.75 ± 0.04	1.54 ± 0.04	1.33 ± 0.03		10.9	0.288

a. Tests made at 8:1 span-depth ratio. Other details of testing in accordance with Method 1031, Federal Specification L-P-406a.

b. Mean value for five to ten specimens. The accompanying plus or minus value is the standard error, S.E.

c. Relative to 77°F value.

TABLE V. Continued:

Material Designation	Orientation of Specimen	Direction of Load	Temp. Test (^{o}F)	Flexural Strength, S_r[a] Mean[b] (10^3lb/in^2)	Flexural Strength, S_r[a] Change[c] (%)	Flexural Modulus of Elasticity: Initial Value, E_i Mean[b] (10^6lb/in^2)	Initial Value, E_i Change[c] (%)	Mean Secant Modulus for Various Ranges of Stress (10^6lb/in^2)	Mean Secant Modulus for Various Ranges of Stress (10^6lb/in^2)	Mean Secant Modulus for Various Ranges of Stress (10^6lb/in^2)	(10^6lb/in^2)	Specific Strength Values $S_r/(Sp.Gr.)^2$ (10^3lb/in^2)	Specific Strength Values $E_i/(Sp.Gr.)^3$ (10^6lb/in^2)
								0-10,000lb/in^2	0-15,000lb/in^2	0-20,000lb/in^2	0-25,000lb/in^2		
S2, High-Strength-Paper Phenolic	Lengthwise	Flatwise	-70	40.7 ± 0.3	+23	2.89 ± 0.02	+19			2.78 ± 0.02	2.71 ± 0.03	20.1	1.01
			77	33.2 ± 0.4		2.42 ± 0.02			2.28 ± 0.01	2.10 ± 0.01		16.5	0.845
			200	19.4 ± 0.2	-42	1.95 ± 0.01	-19	1.80 ± 0.01	1.55 ± 0.01			9.6	0.681
	Crosswise	Flatwise	-70	42.4 ± 1.4	+24	2.92 ± 0.03	+27			2.84 ± 0.02	2.77 ± 0.02	21.0	1.02
			77	34.2 ± 0.6		2.30 ± 0.02			2.24 ± 0.02	2.05 ± 0.01		17.0	0.803
			200	19.8 ± 0.4	-42	1.88 ± 0.02	-18	1.78 ± 0.01	1.51 ± 0.01			9.8	0.656
	Lengthwise	Edgewise	-70	43.7 ± 0.7	+30	3.32 ± 0.07	+25			3.14 ± 0.04	3.06 ± 0.03	21.7	1.16
			77	33.5 ± 0.5		2.65 ± 0.03			2.55 ± 0.02	2.31 ± 0.01		16.6	0.926
			200	20.6 ± 0.3	-39	2.21 ± 0.03	-17	2.16 ± 0.02	1.89 ± 0.02			10.2	0.772
	Crosswise	Edgewise	-70	42.0 ± 0.7	+25	3.12 ± 0.05	+15			3.03 ± 0.02	2.96 ± 0.04	20.8	1.09
			77	33.6 ± 0.4		2.71 ± 0.06			2.60 ± 0.06	2.35 ± 0.05		16.7	0.946
			200	20.8 ± 0.4	-38	2.29 ± 0.02	-16	2.21 ± 0.02	1.89 ± 0.02			10.3	0.800
								0-20,000lb/in^2	0-25,000lb/in^2				
U2, Glass-Fabric Unsaturated-Polyester	Lengthwise	Flatwise	-70	72.1 ± 0.5	+27	2.87 ± 0.01	+11	2.86 ± 0.01	2.78 ± 0.01			22.8	0.509
			77	56.9 ± 0.1		2.59 ± 0.02		2.57 ± 0.02	2.52 ± 0.02			18.0	0.459
			200	37.0± 0.3	-35	1.89 ± 0.02	-27	1.84 ± 0.02	1.80 ± 0.02			11.7	0.335
	Crosswise	Flatwise	-70	59.0 ±0.8	+31	2.72 ± 0.02	+11	2.66 ± 0.02	2.57 ± 0.01			18.6	0.482
			77	45.1 ±0.7		2.45 ± 0.01		2.35 ± 0.02	2.29 ± 0.02			14.2	0.434
			200	27.6 ±0.5	-39	1.82 ± 0.02	-26	1.71 ± 0.02	1.66 ± 0.02			8.7	0.323
	Lengthwise	Edgewise	-70	73.2 ± 0.4	+34	2.94 ± 0.03	+ 9	2.94 ± 0.03	2.92 ± 0.03			23.1	0.521
			77	54.8 ± 0.9		2.70 ± 0.03		2.67 ± 0.03	2.63 ± 0.04			17.3	0.479
			200	43.3 ± 0.9	-21	2.06 ± 0.03	-24	2.00 ± 0.03	1.97 ± 0.03			13.7	0.365
	Crosswise	Edgewise	-70	66.0 ± 0.5	+36	2.76 ± 0.01	+14	2.72 ± 0.02	2.63 ± 0.01			20.8	0.489
			77	48.6 ± 0.5		2.43 ± 0.03		2.37 ± 0.03	2.33 ± 0.03			15.3	0.431
			200	34.5 ± 0.4	-29	1.82 ± 0.01	-25	1.73 ± 0.01	1.68 ± 0.01			10.9	0.323
								0-5,000lb/in^2	0-10,000lb/in^2	0-15,000lb/in^2			
V2, Low-Pressure Grade C Phenolic	Lengthwise	Flatwise	-70	20.8 ± 0.4	+24	1.22 ± 0.02	+49		1.09 ± 0.02	0.79 ± 0.03		12.5	0.568
			77	16.7 ± 0.3		0.82 ± 0.01			0.58 ± 0.01	0.38 ± 0.01		10.0	0.382
			200	11.4 ± 0.2	-32	0.71 ± 0.01	-13	0.63 ± 0.01	0.41 ± 0.02			6.8	0.331
	Crosswise	Flatwise	-70	20.4 ± 0.4	+25	1.27 ± 0.02	+57		1.11 ± 0.01	0.83 ± 0.02		12.3	0.592
			77	16.3 ± 0.2		0.81 ± 0.02			0.59 ± 0.02	0.39 ± 0.01		9.8	0.377
			200	11.5 ± 0.2	-29	0.68 ± 0.01	-16	0.61 ± 0.02	0.41 ± 0.01			6.9	0.317
	Lengthwise	Edgewise	-70	19.8 ± 0.4	+22	1.14 ± 0.01	+44		1.05 ± 0.01	0.78 ± 0.01		11.9	0.531
			77	16.3 ± 0.1		0.79 ± 0.01			0.58 ± 0.01	0.37 ± 0.01		9.8	0.368
			200	11.4 ± 0.2	-30	0.65 ± 0.01	-18	0.59 ± 0.01	0.39 ± 0.01			6.8	0.303
	Crosswise	Edgewise	-70	20.2 ± 0.2	+22	1.21 ± 0.01	+53		1.09 ± 0.01	0.83 ± 0.01		12.1	0.564
			77	16.5 ± 0.2		0.79 ± 0.01			0.60 ± 0.01	0.38 ± 0.01		9.9	0.368
			200	11.5 ± 0.1	-30	0.64 ± 0.01	-19	0.60 ± 0.01	0.41 ± 0.01			6.9	0.298
								0-5,000lb/in^2	0-10,000lb/in^2	0-15,000lb/in^2			
W2, High-Pressure Grade C Phenolic	Lengthwise	Flatwise	-70	22.6 ± 0.3	+23	1.31 ± 0.02	+36		1.23 ± 0.02	1.05 ± 0.04		12.2	0.521
			77	18.3 ± 0.4		0.96 ± 0.02			0.76 ± 0.02	0.58 ± 0.02		9.9	0.382
			200	13.3 ± 0.2	-28	0.80 ± 0.02	-17	0.74 ± 0.01	0.55 ± 0.02			7.2	0.318
	Crosswise	Flatwise	-70	23.9 ± 0.3	+30	1.45 ± 0.04	+46		1.36 ± 0.05	1.17 ± 0.06		12.9	0.576
			77	18.4 ± 0.2		0.99 ± 0.02			0.79 ± 0.02	0.59 ± 0.03		9.9	0.394
			200	13.2 ± 0.1	-28	0.82 ± 0.02	-17	0.76 ± 0.03	0.58 ± 0.03			7.1	0.326
	Lengthwise	Edgewise	-70	23.2 ± 0.4	+30	1.46 ± 0.03	+46		1.38 ± 0.02	1.17 ± 0.04		12.5	0.580
			77	17.9 ± 0.1		1.00 ± 0.03			0.78 ± 0.02	0.59 ± 0.03		9.7	0.398
			200	12.7 ± 0.3	-29	0.75 ± 0.02	-25	0.74 ± 0.02	0.52 ± 0.03			6.9	0.298
	Crosswise	Edgewise	-70	23.3 ± 0.2	+29	1.56 ± 0.01	+51		1.47 ± 0.01	1.32 ± 0.01		12.6	0.620
			77	18.0 ± 0.1		1.03 ± 0.02			0.81 ± 0.02	0.61 ± 0.02		9.7	0.409
			200	12.7 ± 0.2	-29	0.80 ± 0.03	-22	0.77 ± 0.01	0.55 ± 0.02			6.9	0.318

TABLE VI.- EFFECT OF HEATING AT 200° F FOR 24 HOURS ON FLEXURAL PROPERTIES OF LAMINATED MATERIALS.[a]

Material Designation	Orientation of Specimen	Direction of Load	Flexural Strength		Flexural Modulus of Elasticity					
					Initial		Secant			
			No Heating[b] (10^3 lb/in^2)	Heated at 200°F[c] (10^3 lb/in^2)	No Heating[b] (10^6 lb/in^2)	Heated at 200°F[c] (10^6 lb/in^2)	No Heating[b] (10^6 lb/in^2)	Heated at 200°F[c] (10^6 lb/in^2)	No Heating[b] (10^6 lb/in^2)	Heated at 200°F[c] (10^6 lb/in^2)
							0-10,000 lb/in^2			
I2, Grade C Phenolic	Crosswise	Flatwise	20.7 ± 0.3	18.8 ± 0.2	1.07 ± 0.07	1.07 ± 0.02	1.02 ± 0.04	0.99 ± 0.02		
	Lengthwise	Edgewise	21.2 ± 0.2	19.7 ± 0.3	1.14 ± 0.03	1.11 ± 0.03	1.09 ± 0.02	1.04 ± 0.01		
							0-7,500 lb/in^2			
E2, Asbestos-Fabric Phenolic	Crosswise	Flatwise	8.9 ± 0.2	9.6 ± 0.1	0.99 ± 0.01	1.11 ± 0.01	0.92 ± 0.01	1.04 ± 0.02		
	Crosswise	Edgewise	9.4 ± 0.1	9.9 ± 0.2	0.97 ± 0.02	1.07 ± 0.01	0.90 ± 0.02	0.99 ± 0.02		
							0-10,000 lb/in^2			
L2, Low-Pressure Cotton-Fabric Phenolic	Crosswise	Flatwise	16.1 ± 0.2	15.4 ± 0.1	0.80 ± 0.01	0.86 ± 0.01	0.67 ± 0.01	0.72 ± 0.01		
	Crosswise	Edgewise	17.5 ± 0.4	15.7 ± 0.1	0.76 ± 0.02	0.88 ± 0.02	0.64 ± 0.01	0.72 ± 0.01		
							0-15,000 lb/in^2			
S2, High-Strength-Paper Phenolic	Lengthwise	Flatwise	33.2 ± 0.4	27.2 ± 0.6	2.42 ± 0.02	2.43 ± 0.02	2.28 ± 0.01	2.23 ± 0.01		
	Crosswise	Edgewise	33.6 ± 0.4	30.4 ± 0.1	2.71 ± 0.06	2.88 ± 0.05	2.60 ± 0.06	2.64 ± 0.02		
							0-20,000 lb/in^2		0-25,000 lb/in^2	
U2, Glass-Fabric Unsaturated-Polyester	Crosswise	Flatwise	45.1 ± 0.7	53.0 ± 0.3	2.45 ± 0.01	2.55 ± 0.01	2.35 ± 0.02	2.48 ± 0.01	2.29 ± 0.02	2.44 ± 0.01
	Crosswise	Edgewise	48.6 ± 0.5	51.3 ± 0.5	2.43 ± 0.02	2.52 ± 0.03	2.37 ± 0.03	2.46 ± 0.03	2.33 ± 0.03	2.42 ± 0.03
							0-10,000 lb/in^2			
V2, Low-Pressure Grade C Phenolic	Lengthwise	Flatwise	16.7 ± 0.3	14.7 ± 0.2	0.82 ± 0.01	0.79 ± 0.01	0.58 ± 0.01	0.56 ± 0.01		
	Crosswise	Flatwise	16.3 ± 0.2	14.6 ± 0.2	0.81 ± 0.02	0.77 ± 0.01	0.59 ± 0.02	0.59 ± 0.01		
	Lengthwise	Edgewise	16.3 ± 0.1	14.7 ± 0.1	0.79 ± 0.01	0.74 ± 0.01	0.58 ± 0.01	0.56 ± 0.01		
	Crosswise	Edgewise	16.5 ± 0.2	14.5 ± 0.5	0.79 ± 0.01	0.74 ± 0.02	0.60 ± 0.01	0.59 ± 0.01		
							0-10,000 lb/in^2		0-15,000 lb/in^2	
W2, High-Pressure Grade C Phenolic	Lengthwise	Flatwise	18.3 ± 0.4	16.9 ± 0.4	0.96 ± 0.02	0.89 ± 0.02	0.76 ± 0.02	0.76 ± 0.03	0.58 ± 0.02	0.57 ± 0.03
	Crosswise	Flatwise	18.4 ± 0.2	17.2 ± 0.2	0.99 ± 0.02	0.91 ± 0.03	0.79 ± 0.02	0.79 ± 0.03	0.59 ± 0.03	0.59 ± 0.03
	Lengthwise	Edgewise	17.9 ± 0.1	16.5 ± 0.2	1.00 ± 0.03	0.91 ± 0.01	0.78 ± 0.02	0.78 ± 0.02	0.59 ± 0.03	0.58 ± 0.03
	Crosswise	Edgewise	18.0 ± 0.1	16.3 ± 0.2	1.03 ± 0.02	0.94 ± 0.02	0.81 ± 0.02	0.81 ± 0.02	0.61 ± 0.02	0.60 ± 0.02
							0-15,000 lb/in^2		0-20,000 lb/in^2	
Z2, Rayon-Cotton-Fabric Phenolic	Lengthwise	Flatwise	34.4 ± 0.5	31.0 ± 0.4	1.58 ± 0.02	1.71 ± 0.01	1.42 ± 0.03	1.56 ± 0.004	1.23 ± 0.04	1.42 ± 0.004
	Crosswise	Flatwise	32.7 ± 0.5	30.8 ± 0.7	1.40 ± 0.01	1.39 ± 0.02	1.25 ± 0.02	1.24 ± 0.02	1.09 ± 0.02	1.09 ± 0.02
							0-20,000 lb/in^2		0-25,000 lb/in^2	
AB2, Glass-Fabric Unsaturated-Polyester	Lengthwise	Flatwise	53.2 ± 0.1	57.8 ± 0.7	2.88 ± 0.01	2.91 ± 0.04	2.80 ± 0.02	2.80 ± 0.02	2.77 ± 0.02	2.77 ± 0.02

a. Tests were made in accordance with Method 1031, Federal Specification L-P-406a, using an 8:1 span-depth ratio. Each value in the table represents the mean for five specimens.

b. Data from table V; specimens conditioned and tested at 77°F and 50% relative humidity.

c. Specimens tested at 77°F after being allowed to cool to room temperature for 1 to 2 hours in a desiccator containing calcium chloride.

TABLE VII.- EFFECT OF SPAN-DEPTH RATIO ON FLEXURAL PROPERTIES OF LAMINATED PLASTICS[a]

Material Designation	Orientation of Specimen	Direction of Load	Flexural Strength At Span-Depth Ratio: 8:1 (10^3lb/in^2)	Flexural Strength At Span-Depth Ratio: 16:1 (10^3lb/in^2)	Flexural Modulus of Elasticity: Initial Modulus of Elasticity At Span-Depth Ratio: 8:1 (10^6lb/in^2)	Flexural Modulus of Elasticity: Initial Modulus of Elasticity At Span-Depth Ratio: 16:1 (10^6lb/in^2)	Flexural Modulus of Elasticity: Secant Modulus of Elasticity At Span-Depth Ratio: 8:1 (10^6lb/in^2)	Flexural Modulus of Elasticity: Secant Modulus of Elasticity At Span-Depth Ratio: 16:1 (10^6lb/in^2)	Flexural Modulus of Elasticity: Secant Modulus of Elasticity At Span-Depth Ratio: 8:1 (10^6lb/in^2)	Flexural Modulus of Elasticity: Secant Modulus of Elasticity At Span-Depth Ratio: 16:1 (10^6lb/in^2)
							0-10,000 lb/in^2			
I2, Grade C Phenolic	Lengthwise	Flatwise	22.2 ± 0.3	20.9 ± 0.1	1.06 ± 0.02	1.24 ± 0.02	1.07 ± 0.02	1.10 ± 0.02		
	Crosswise	Flatwise	20.7 ± 0.3	19.7 ± 0.3	1.07 ± 0.07	1.22 ± 0.03	1.02 ± 0.04	1.06 ± 0.02		
	Lengthwise	Edgewise	21.2 ± 0.2	19.8 ± 0.2	1.14 ± 0.03	1.30 ± 0.08	1.09 ± 0.02	1.09 ± 0.02		
	Crosswise	Edgewise	21.4 ± 0.4	19.5 ± 0.1	1.11 ± 0.08	1.31 ± 0.04	1.04 ± 0.07	1.07 ± 0.03		
							0-5,000 lb/in^2		0-7,500 lb/in^2	
F2, Asbestos-Fabric Phenolic	Lengthwise	Flatwise	16.3 ± 0.6		1.20 ± 0.02		1.20 ± 0.02			
	Crosswise	Flatwise	8.9 ± 0.2		0.99 ± 0.01		0.99 ± 0.01			
	Lengthwise	Edgewise	16.4 ± 0.2		1.15 ± 0.02		1.15 ± 0.02			
	Crosswise	Edgewise	9.4 ± 0.1	9.0 ± 0.1	0.97 ± 0.02	1.06 ± 0.02	0.97 ± 0.02	1.02 ± 0.02	0.90 ± 0.02	0.92 ± 0.02
							0-10,000 lb/in^2			
L2, Low-Pressure Cotton-Fabric Phenolic	Lengthwise	Flatwise	18.4 ± 0.2		0.80 ± 0.01		0.67 ± 0.01			
	Crosswise	Flatwise	18.1 ± 0.2		0.80 ± 0.01		0.67 ± 0.01			
	Lengthwise	Edgewise	17.5 ± 0.2		0.78 ± 0.01		0.65 ± 0.01			
	Crosswise	Edgewise	17.5 ± 0.4	16.5 ± 0.2	0.76 ± 0.02	0.87 ± 0.01	0.64 ± 0.01	0.64 ± 0.01		
							0-20,000 lb/in^2			
S2, High-Strength-Paper Phenolic	Lengthwise	Flatwise	33.2 ± 0.4	32.4 ± 0.2	2.42 ± 0.02	2.54 ± 0.02	2.10 ± 0.01	2.15 ± 0.03		
	Crosswise	Flatwise	34.2 ± 0.6	32.4 ± 0.5	2.30 ± 0.02	2.52 ± 0.03	2.05 ± 0.01	2.12 ± 0.02		
	Lengthwise	Edgewise	33.5 ± 0.5	32.6 ± 0.4	2.65 ± 0.03	2.57 ± 0.04	2.31 ± 0.01	2.17 ± 0.02		
	Crosswise	Edgewise	33.6 ± 0.4	31.8 ± 0.5	2.71 ± 0.06	2.54 ± 0.03	2.35 ± 0.05	2.12 ± 0.04		
							0-20,000 lb/in^2		0-25,000 lb/in^2	
U2, Glass-Fabric Unsaturated-Polyester	Lengthwise	Flatwise	56.9 ± 0.1	55.7 ± 0.7	2.59 ± 0.02	2.82 ± 0.05	2.57 ± 0.02	2.70 ± 0.05	2.52 ± 0.02	2.63 ± 0.04
	Crosswise	Flatwise	45.1 ± 0.7	44.5 ± 0.4	2.45 ± 0.01	2.56 ± 0.02	2.35 ± 0.02	2.39 ± 0.02	2.29 ± 0.02	2.33 ± 0.01
	Lengthwise	Edgewise	54.8 ± 0.9	54.2 ± 0.5	2.70 ± 0.03	2.80 ± 0.02	2.67 ± 0.03	2.71 ± 0.02	2.63 ± 0.04	2.62 ± 0.01
	Crosswise	Edgewise	48.6 ± 0.5	45.1 ± 0.4	2.43 ± 0.03	2.57 ± 0.02	2.37 ± 0.03	2.40 ± 0.02	2.33 ± 0.03	2.32 ± 0.02
							0-10,000 lb/in^2			
V2, Low-Pressure Grade C Phenolic	Lengthwise	Flatwise	16.7 ± 0.3	15.3 ± 0.1	0.82 ± 0.01	0.84 ± 0.01	0.58 ± 0.01	0.56 ± 0.01		
	Crosswise	Flatwise	16.3 ± 0.2	15.0 ± 0.2	0.81 ± 0.02	0.82 ± 0.01	0.59 ± 0.02	0.54 ± 0.02		
	Lengthwise	Edgewise	16.3 ± 0.1	15.2 ± 0.2	0.79 ± 0.01	0.84 ± 0.02	0.58 ± 0.01	0.58 ± 0.01		
	Crosswise	Edgewise	16.5 ± 0.2	14.8 ± 0.1	0.79 ± 0.01	0.80 ± 0.01	0.60 ± 0.01	0.54 ± 0.01		
							0-10,000 lb/in^2		0-15,000 lb/in^2	
W2, High-Pressure Grade C Phenolic	Lengthwise	Flatwise	18.3 ± 0.4	17.1 ± 0.2	0.96 ± 0.02	1.03 ± 0.03	0.76 ± 0.02	0.78 ± 0.04	0.58 ± 0.02	0.58 ± 0.04
	Crosswise	Flatwise	18.4 ± 0.2	17.4 ± 0.1	0.99 ± 0.02	1.02 ± 0.05	0.79 ± 0.02	0.76 ± 0.06	0.59 ± 0.03	0.55 ± 0.06
	Lengthwise	Edgewise	17.9 ± 0.1	17.1 ± 0.1	1.00 ± 0.03	1.01 ± 0.02	0.78 ± 0.02	0.76 ± 0.04	0.59 ± 0.03	
	Crosswise	Edgewise	18.0 ± 0.1	16.6 ± 0.1	1.03 ± 0.02	1.00 ± 0.04	0.81 ± 0.02	0.74 ± 0.06	0.61 ± 0.02	
							0-15,000 lb/in^2			
Z2, Rayon-Cotton-Fabric Phenolic	Lengthwise	Flatwise	34.4 ± 0.5	35.0 ± 0.4	1.58 ± 0.02	1.76 ± 0.03	1.42 ± 0.03	1.58 ± 0.03		
	Crosswise	Flatwise	32.7 ± 0.6	30.4 ± 0.3	1.40 ± 0.01	1.42 ± 0.02	1.25 ± 0.02	1.20 ± 0.04		
	Lengthwise	Edgewise	33.4 ± 0.5	31.9 ± 0.3	1.57 ± 0.03	1.66 ± 0.02	1.43 ± 0.03	1.47 ± 0.01		
	Crosswise	Edgewise	31.7 ± 0.2	29.1 ± 0.4	1.50 ± 0.01	1.48 ± 0.04	1.37 ± 0.01	1.21 ± 0.04		
							0-15,000 lb/in^2			
AB2, Glass-Fabric Unsaturated-Polyester	Lengthwise	Flatwise	53.2 ± 0.1	52.1 ± 0.5	2.88 ± 0.01	3.14 ± 0.02	2.80 ± 0.02	2.97 ± 0.03		
	Crosswise	Flatwise	46.0 ± 0.7		2.84 ± 0.03		2.61 ± 0.01			
	Lengthwise	Edgewise	60.8 ± 0.5	57.9 ± 0.8	2.89 ± 0.02	3.18 ± 0.04	2.87 ± 0.01	2.95 ± 0.03		
	Crosswise	Edgewise	53.5 ± 0.7		2.82 ± 0.02		2.66 ± 0.01			

a. Specimens were conditioned and tested at 77°F and 50% relative humidity in accordance with Method 1031, Federal Specification L-P-406a. Each value in the table represents the mean for five to ten specimens. The accompanying plus or minus value is the standard error.

TABLE VIII.- FLEXURAL STRENGTH OF LAMINATES AT VARIOUS TEMPERATURES AND RELATIVE HUMIDITIES[a].

Material Designation	Flexural Strength 77°F 50% R.H.[b] (10^3lb/in^2)	Flexural Strength 150°F 90% R.H.[c] (10^3lb/in^2)	Flexural Strength 200°F < 6% R.H.[d] (10^3lb/in^2)
I2, Grade C Phenolic	22.2 ± 0.3	19.8 ± 0.2	14.5 ± 0.1
S2, High-Strength-Paper Phenolic	33.2 ± 0.4	13.2 ± 0.6	19.4 ± 0.2
V2, Low-Pressure Grade C Phenolic	16.7 ± 0.3	7.0 ± 0.1	11.4 ± 0.2
W2, High-Pressure Grade C Phenolic	18.3 ± 0.4	15.4 ± 0.3	13.3 ± 0.2
Z2, Rayon-Cotton-Fabric Phenolic	34.4 ± 0.5	26.0 ± 0.3	25.8 ± 0.5
AB2, Glass-Fabric Unsaturated-Polyester	53.2 ± 0.1	34.7 ± 0.4	33.8 ± 0.8

a. Lengthwise specimens tested flatwise. Tests were made in accordance with Method 1031, Federal Specification L-P-406a, using an 8:1 span-depth ratio. Each value in the table represents the mean for five specimens.

b. Data from table V; specimens conditioned and tested at 77°F and 50% relative humidity.

c. Specimens tested at 150°F and 90% relative humidity after 24 hours at the test conditions.

d. Data from table V; specimens tested at 200°F and less than 6% relative humidity after 24 hours at the test conditions.

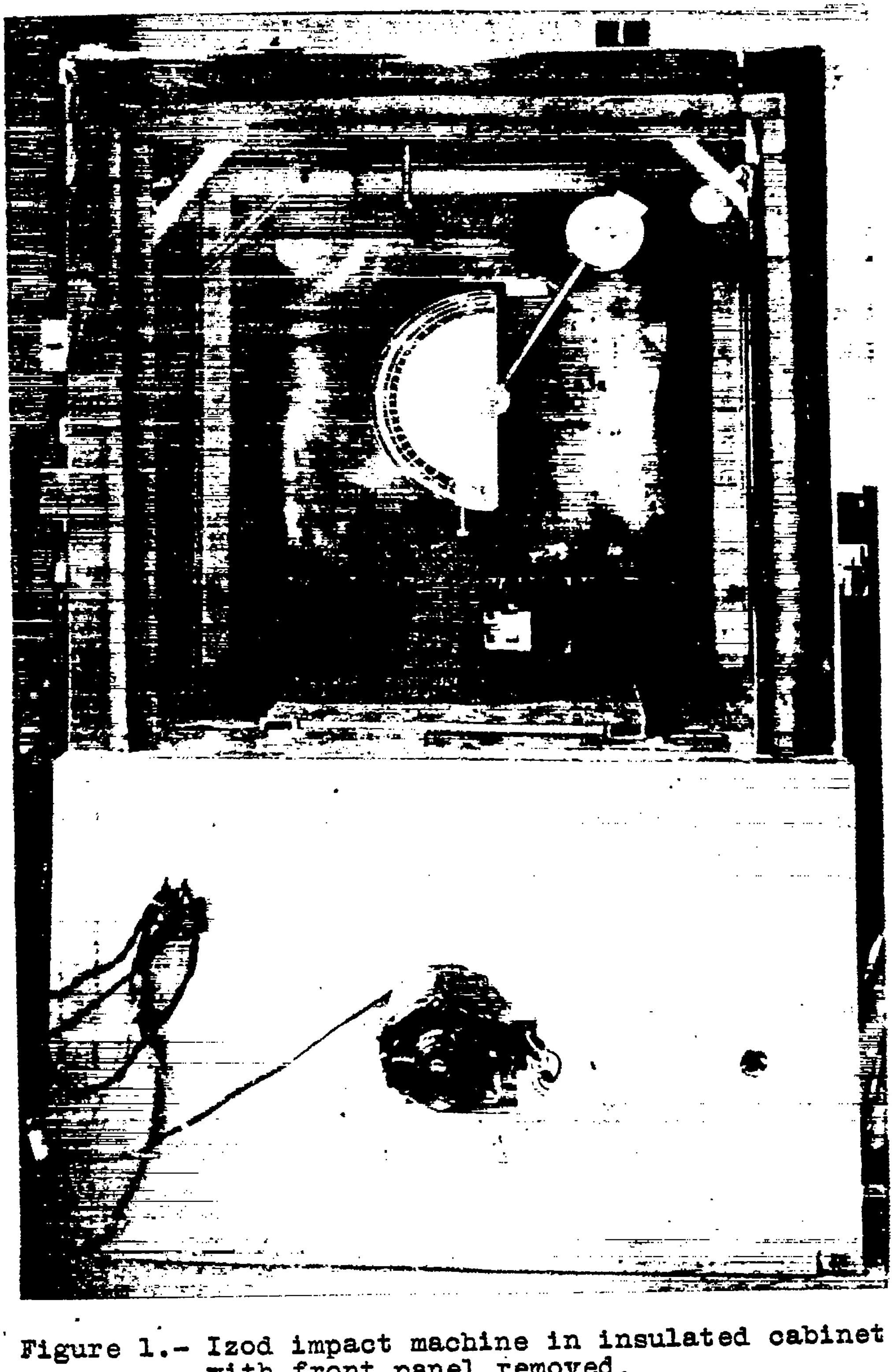

Figure 1.- Izod impact machine in insulated cabinet with front panel removed.

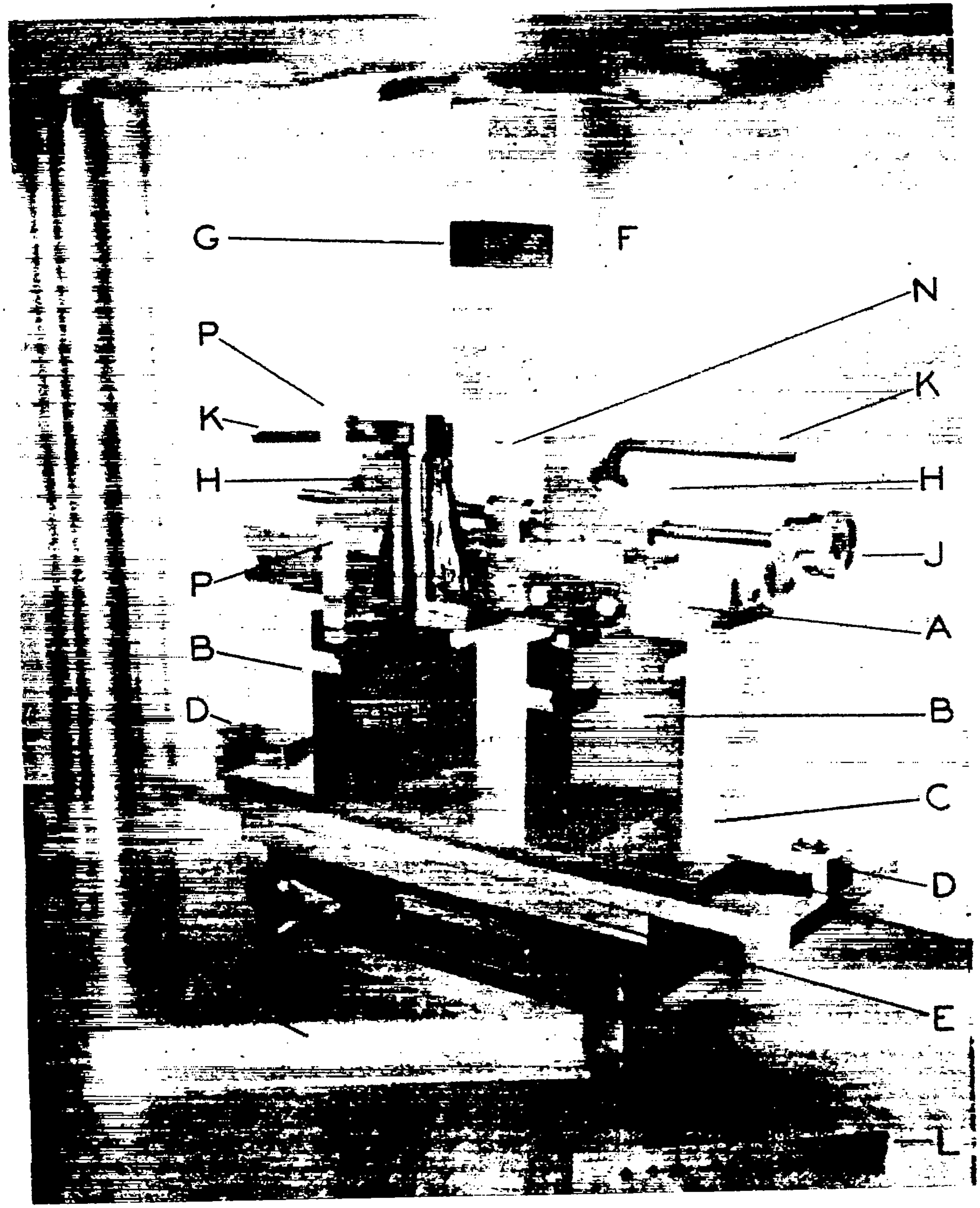

Figure 2.- Adjustable-span flexural jig used for high- and low-temperature testing.

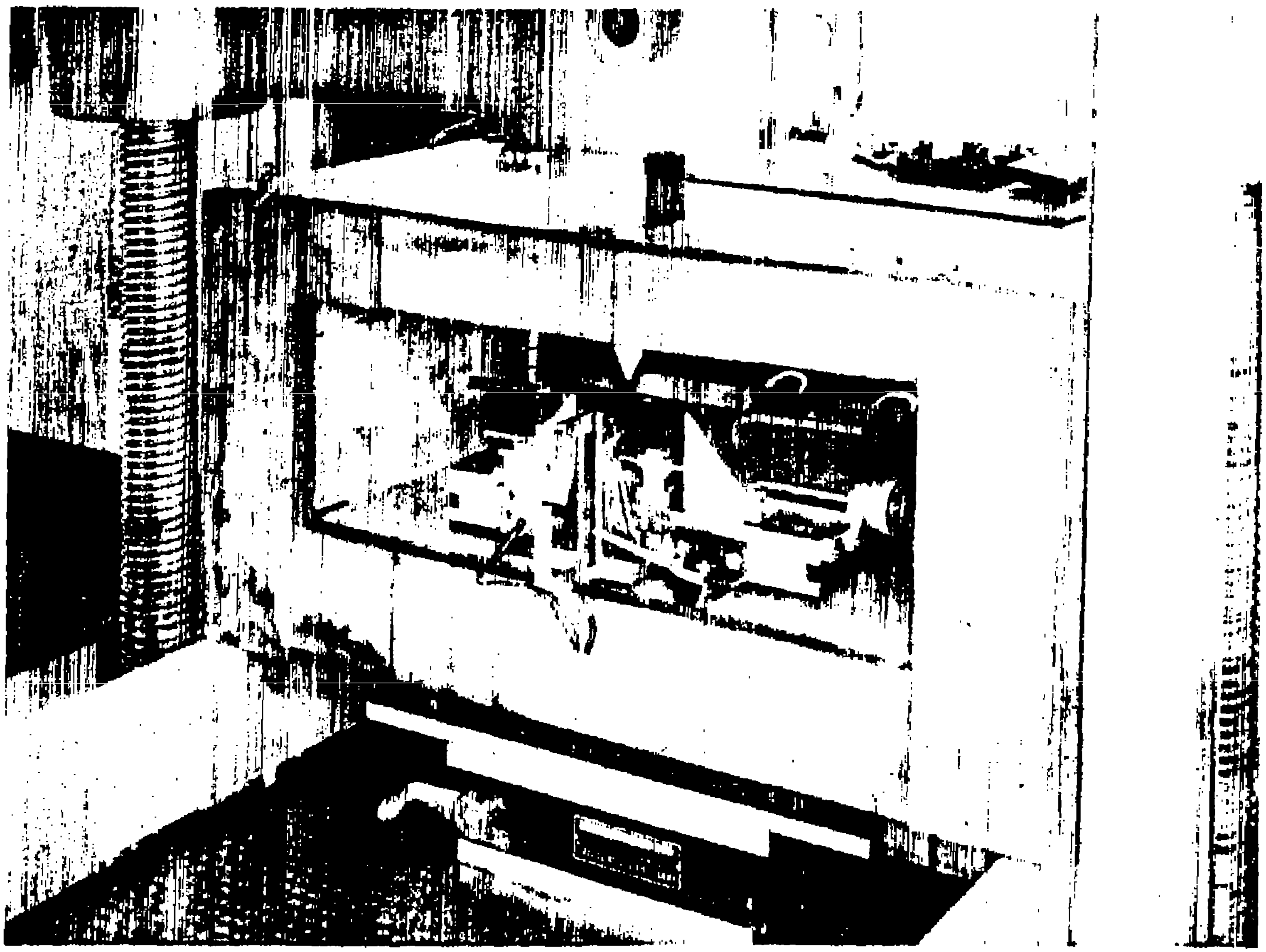

Figure 3,- Flexural apparatus in insulated cabinet with front panel removed; a specimen is in place.

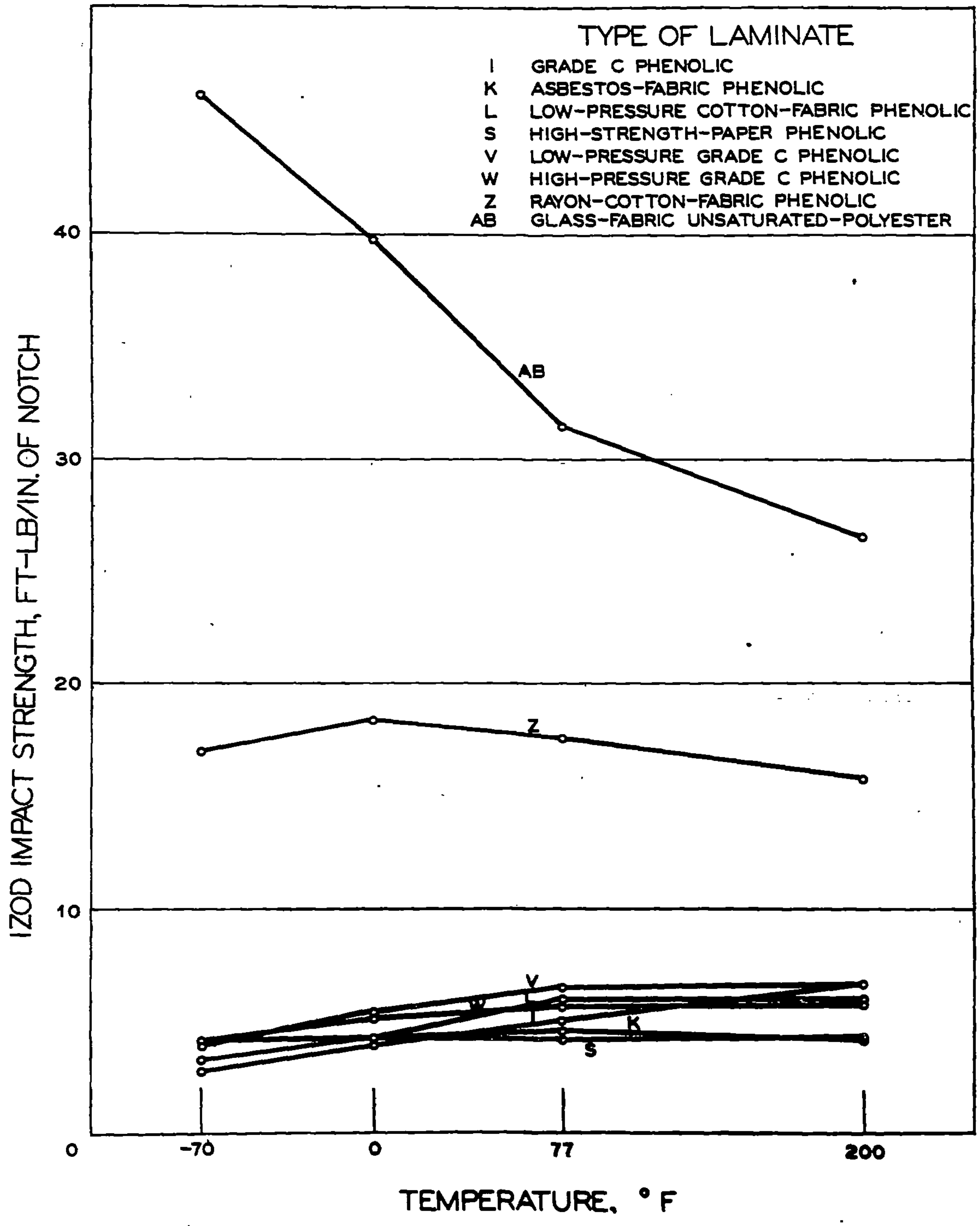

Figure 4a.- Variation of Izod impact strength with temperature for 1/2-inch-thick laminates. Lengthwise specimens tested flatwise.

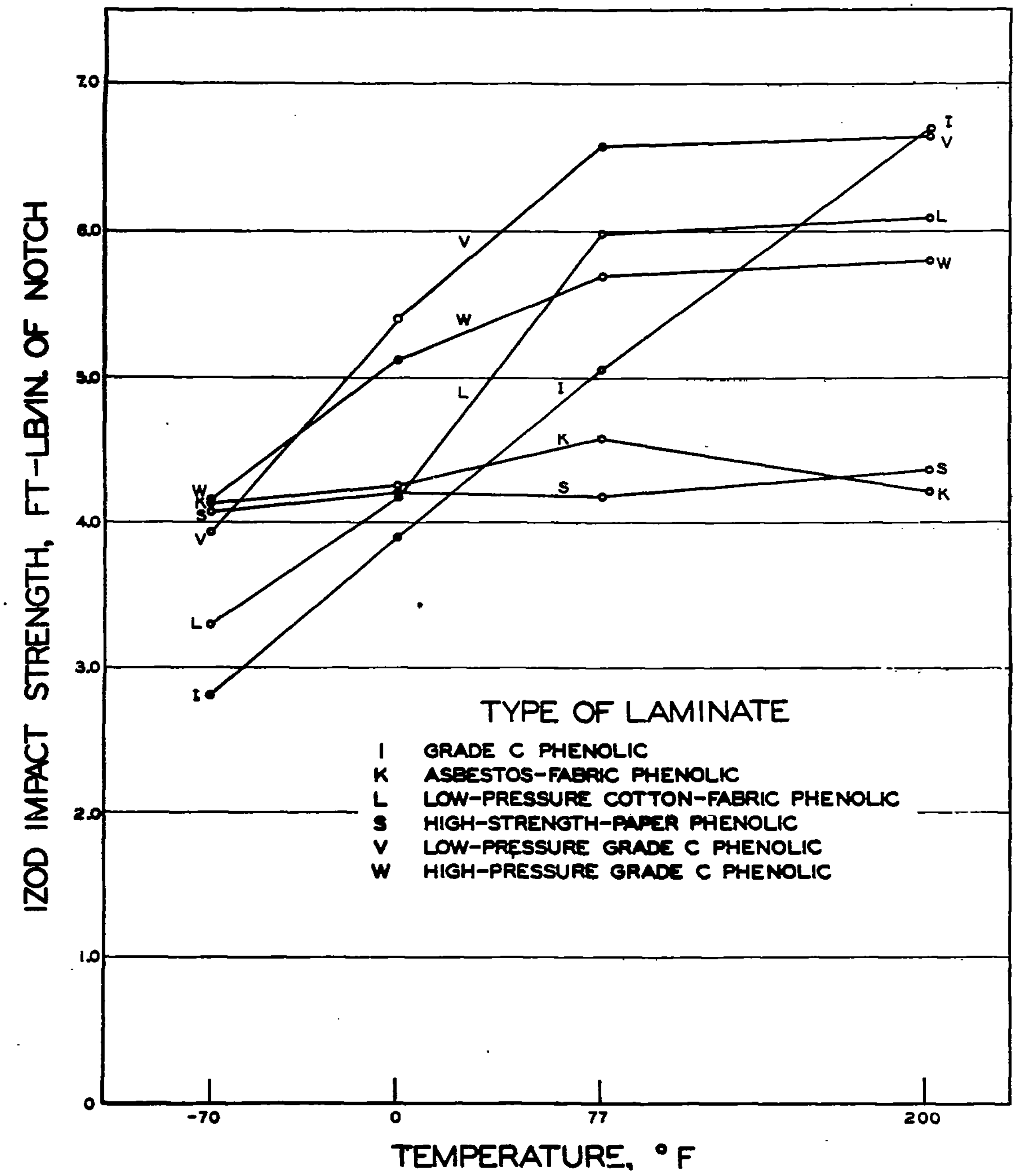

Figure 4b.- Variation of Izod impact strength with temperature for 1/2-inch-thick laminates. Lengthwise specimens tested flatwise.

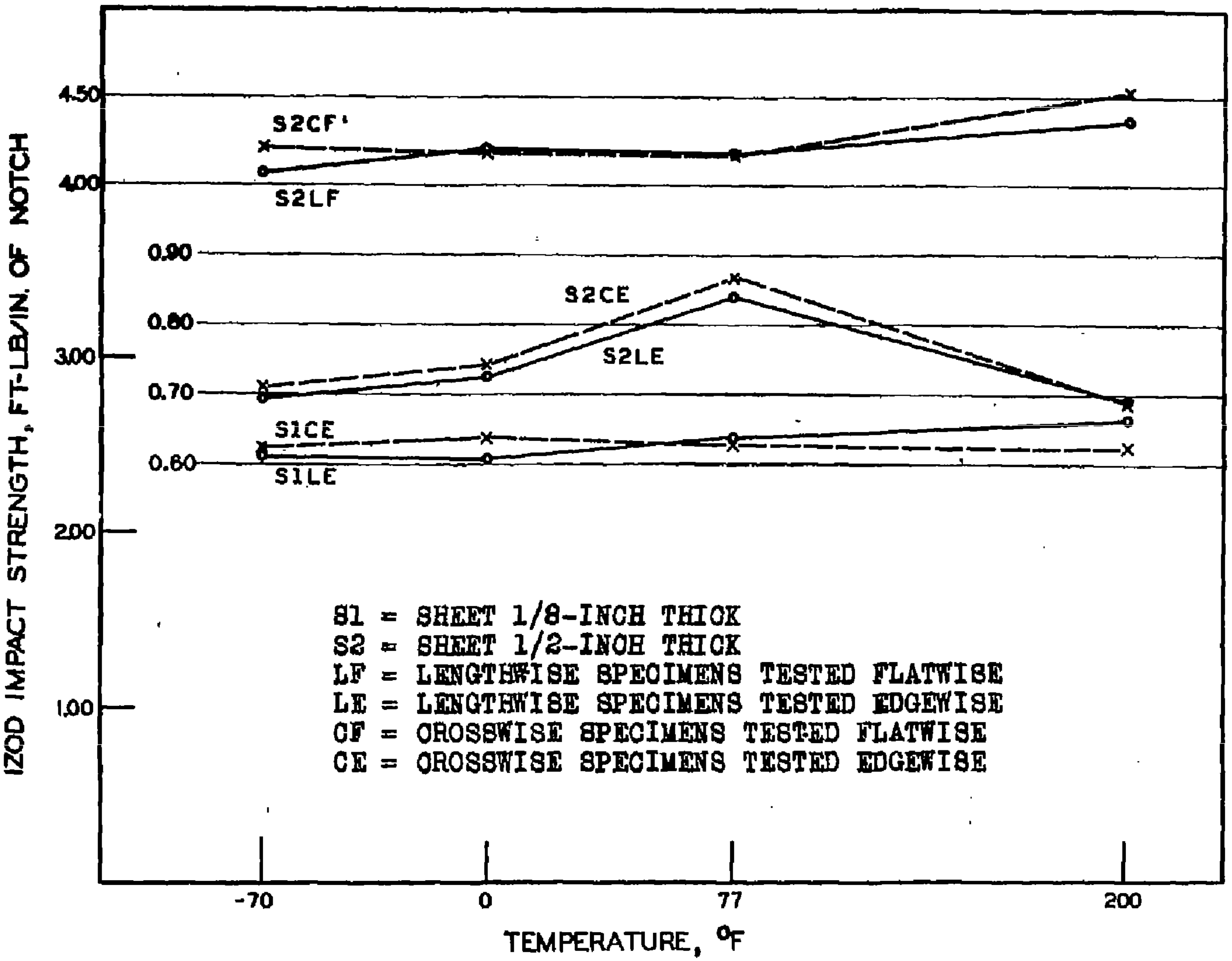

Figure 5.- Variation of Izod impact strength with temperature for high-strength-paper phenolic laminate.

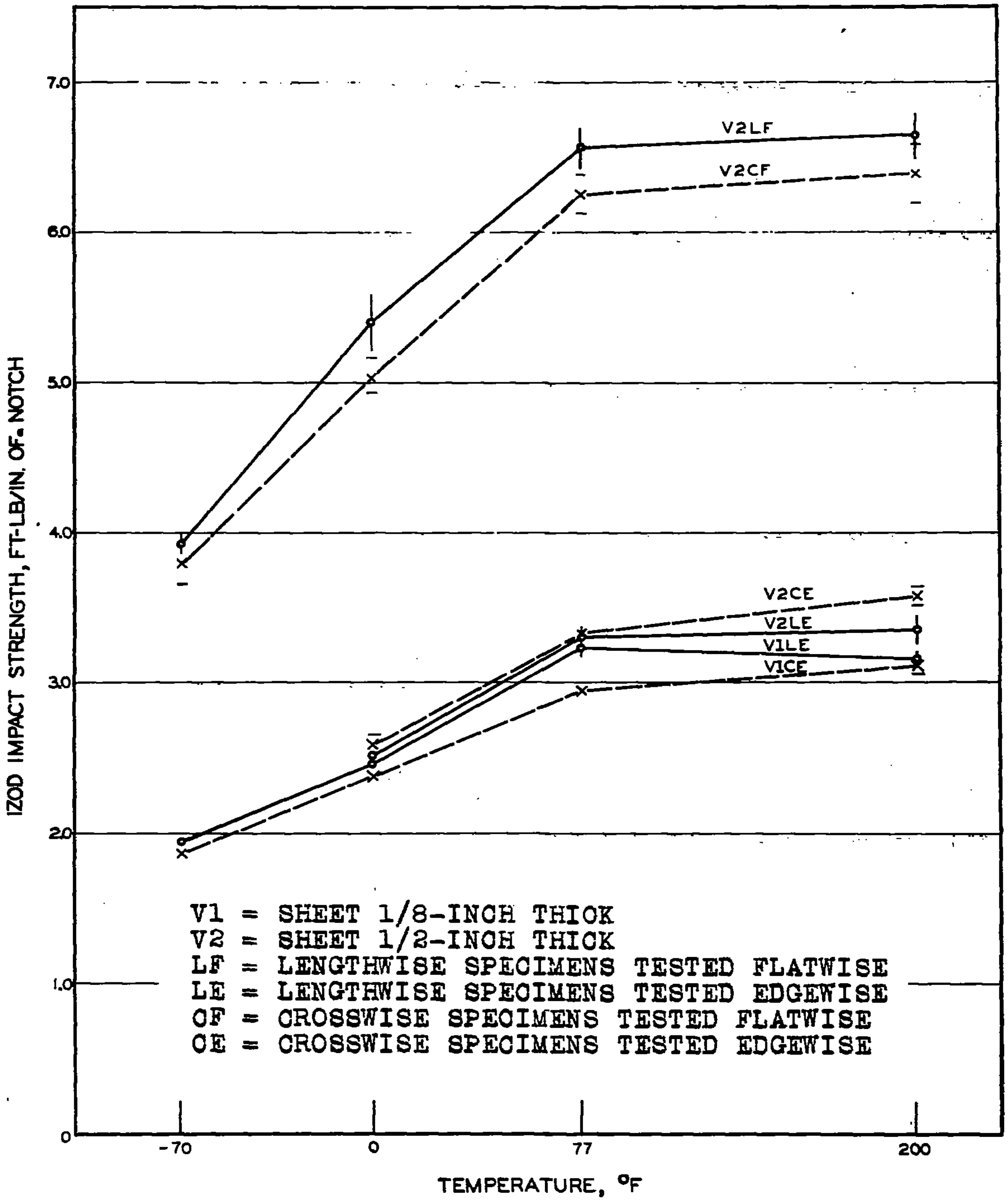

Figure 6.- Variation of Izod impact strength with temperature for low-pressure grade C cotton-fabric phenolic laminate. Mean value ± standard error is indicated by ϕ or $\bar{\underline{x}}$.

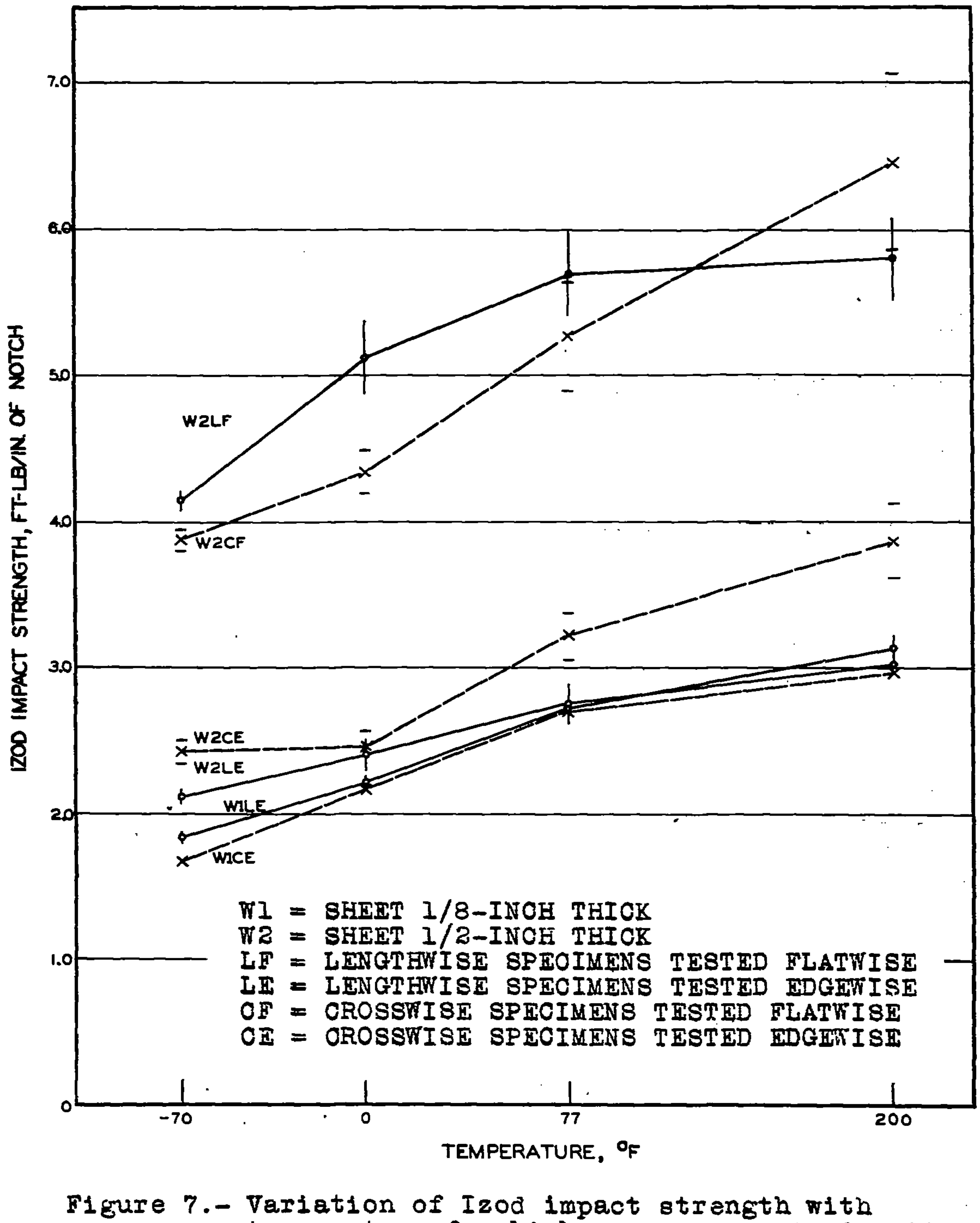

Figure 7.- Variation of Izod impact strength with temperature for high-pressure grade C cotton-fabric phenolic laminate. Mean value ± standard error is indicated by ɸ or $\bar{X}$.

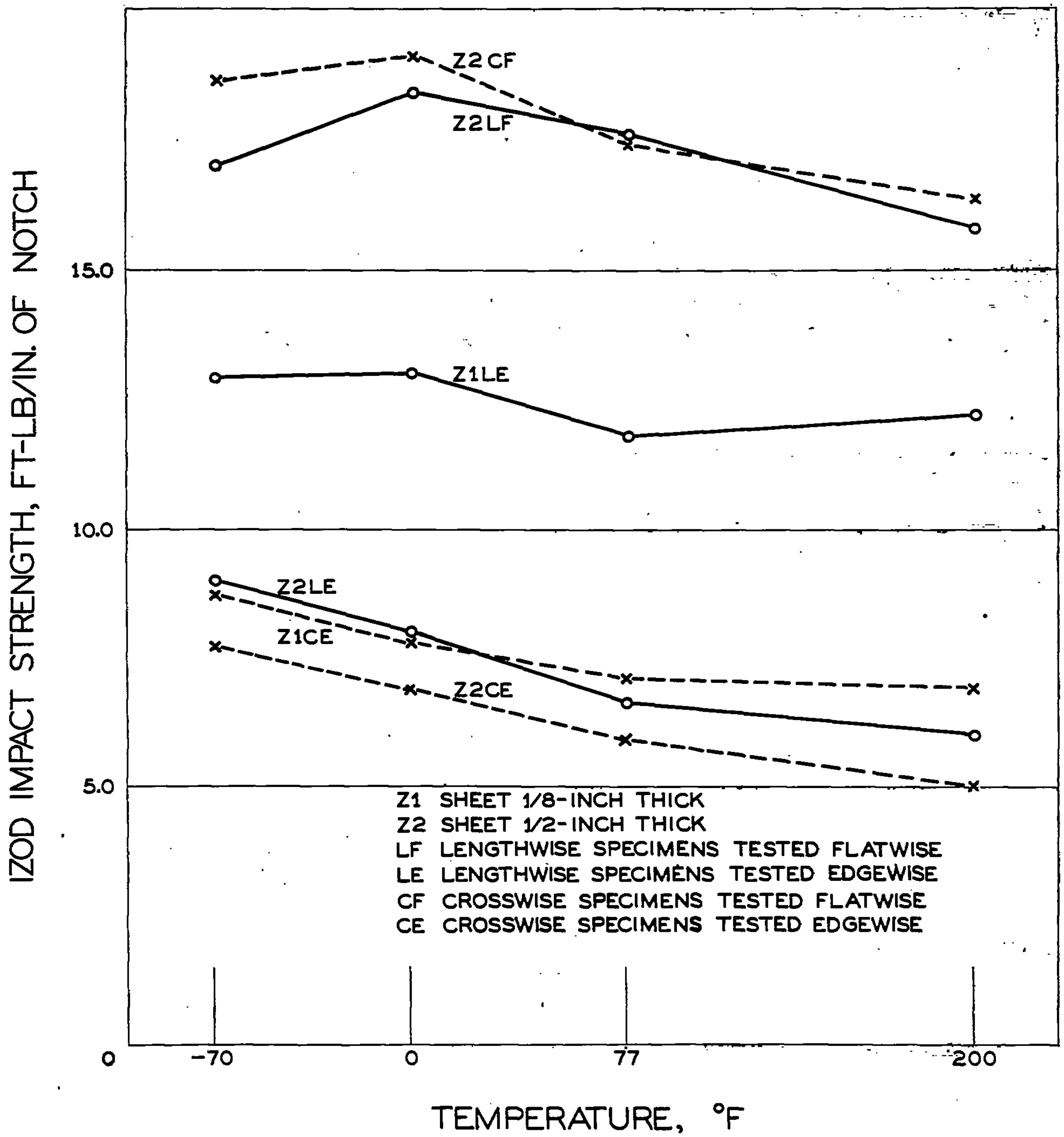

Figure 8.- Variation of Izod impact strength with temperature for rayon-cotton-fabric phenolic laminate.

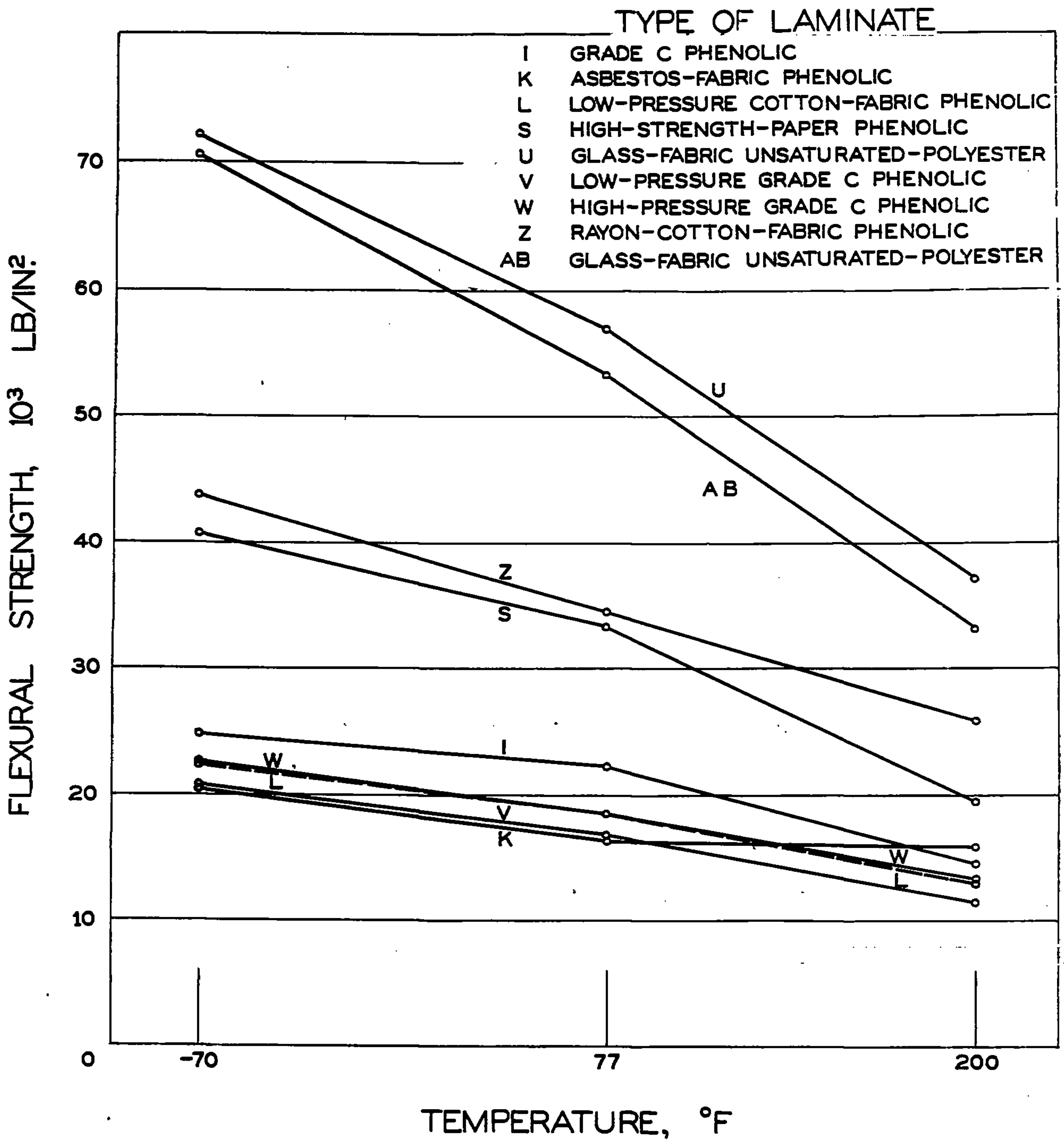

Figure 9.- Variation of flexural strength with temperature for 1/2-inch thick laminates. Lengthwise specimens tested flatwise. Span-depth ratio 8:1.

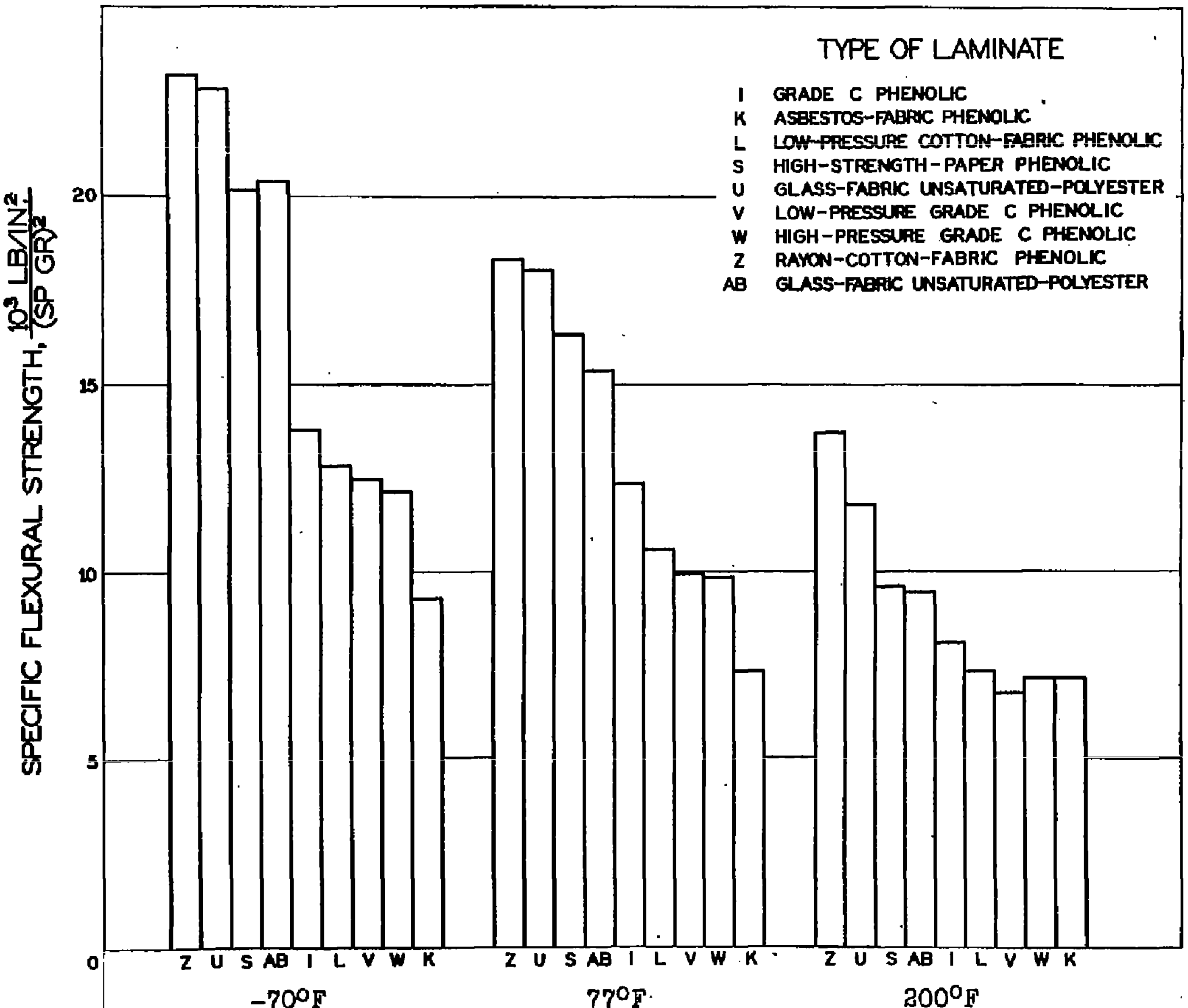

Figure 10.- Comparison of specific flexural strength of 1/2-inch-thick laminates at three temperatures. Lengthwise specimens tested flatwise. Span-depth ratio 8:1.

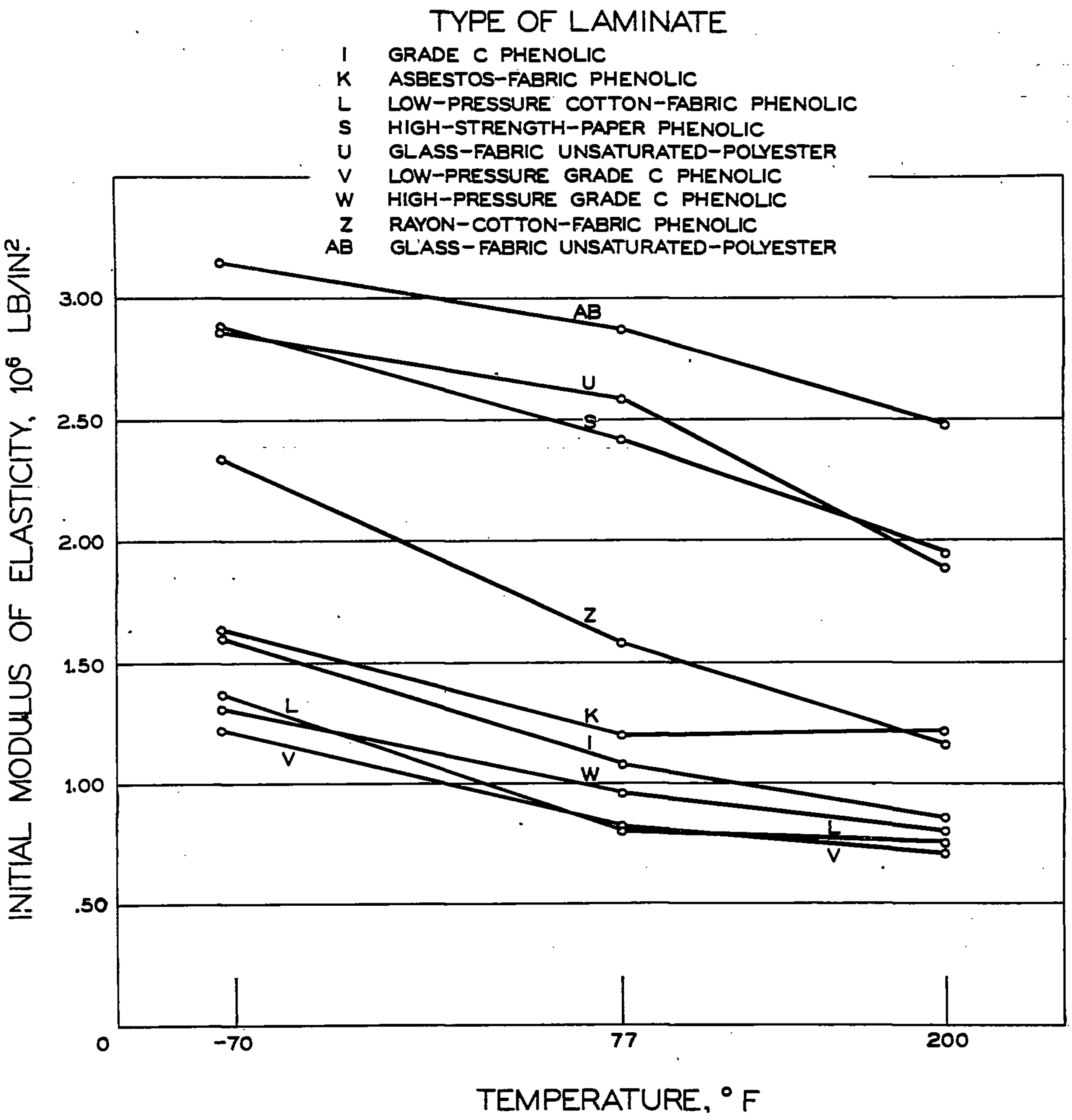

Figure 11.- Variation of initial flexural modulus of elasticity with temperature for 1/2-inch-thick laminates. Lengthwise specimens tested flatwise. Span-depth ratio 8:1.

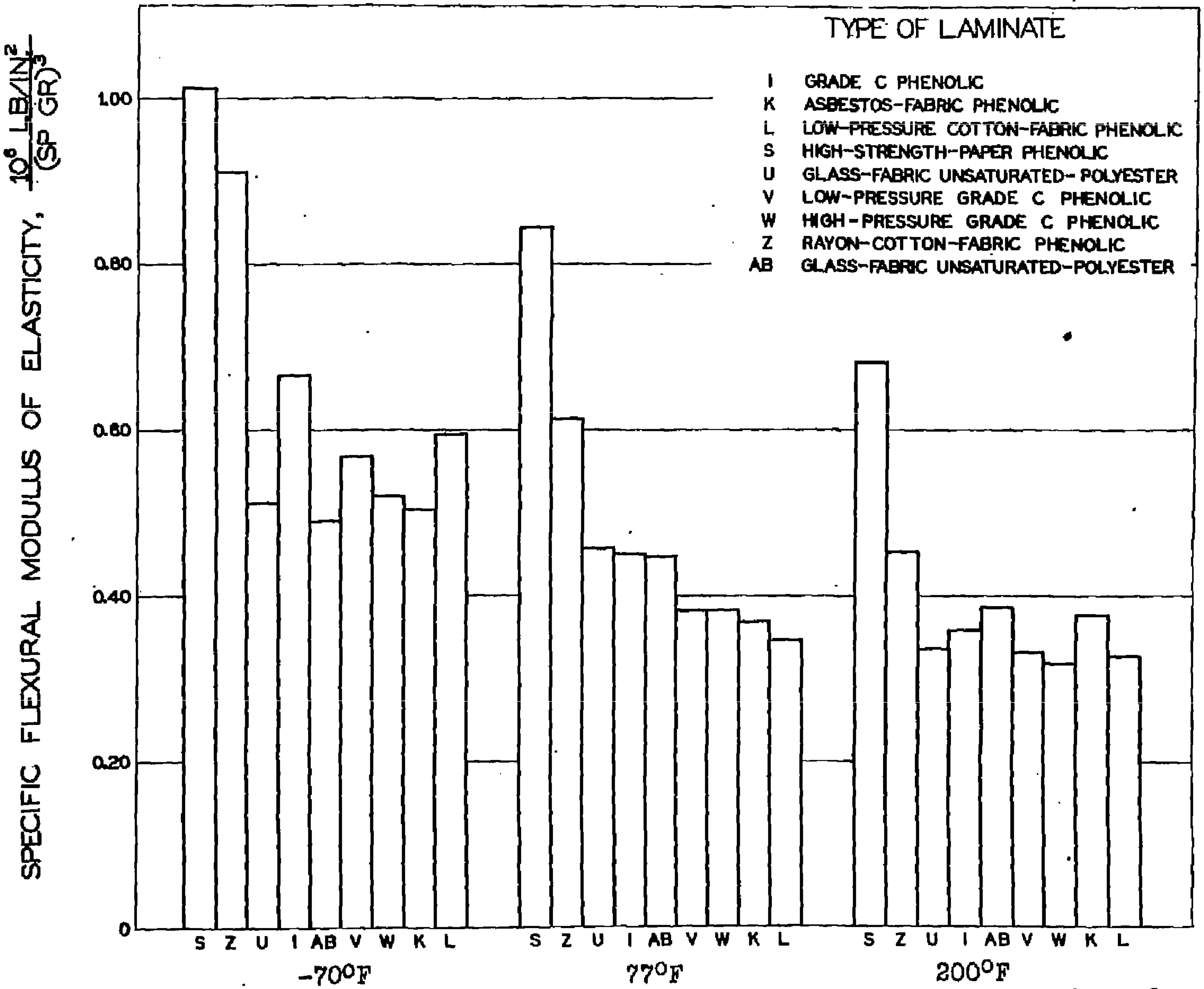

Figure 12.- Comparison of specific flexural modulus of elasticity of 1/2-inch-thick laminates at three temperatures. Lengthwise specimens tested flatwise. Span-depth ratio 8:1.

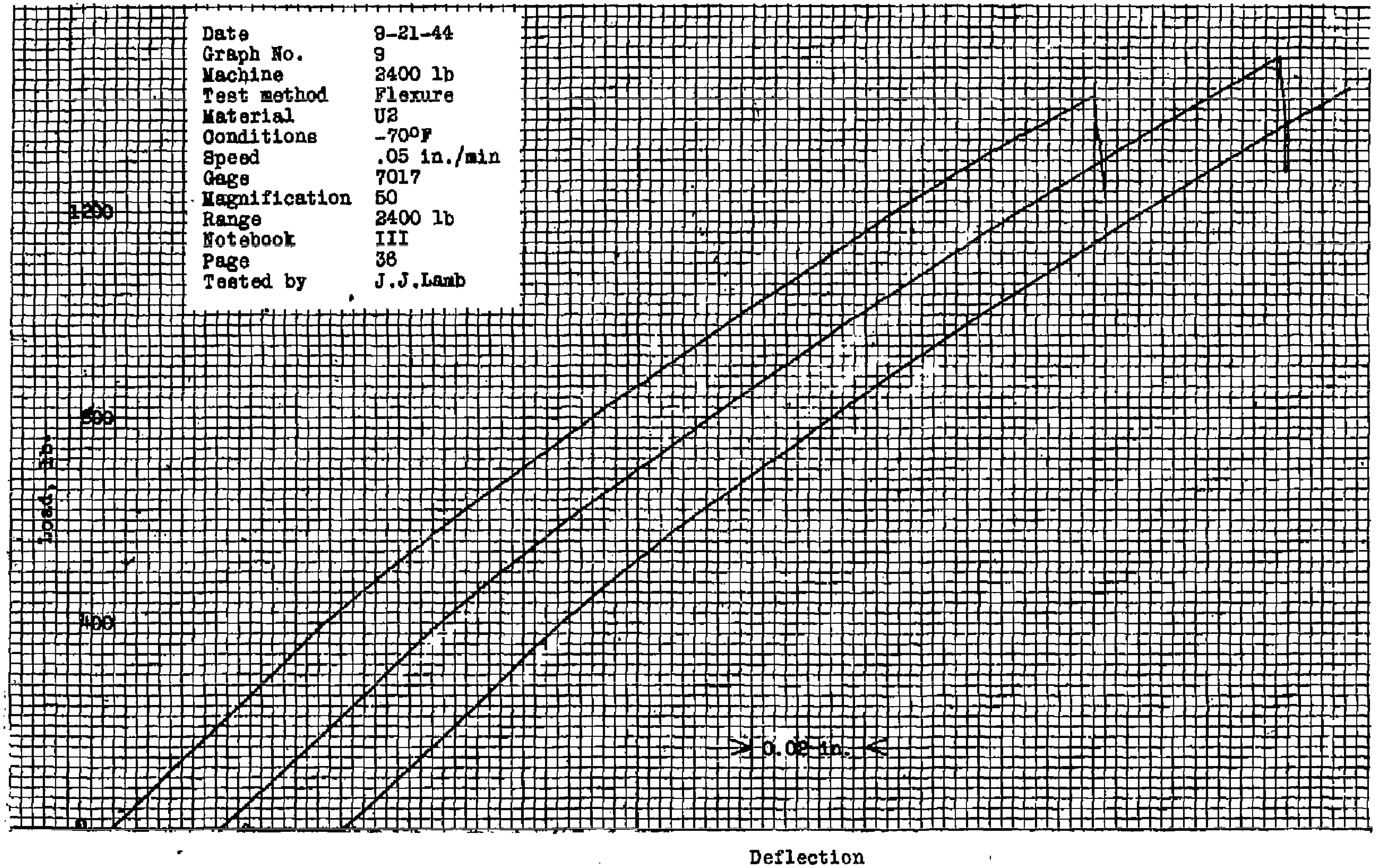

Figure 13.- Typical flexural load-deflection curves at -70°F obtained with automatic stress-strain recorder. Crosswise specimens of glass-fabric laminate, U2, tested flatwise. Span-depth ratio 8:1.

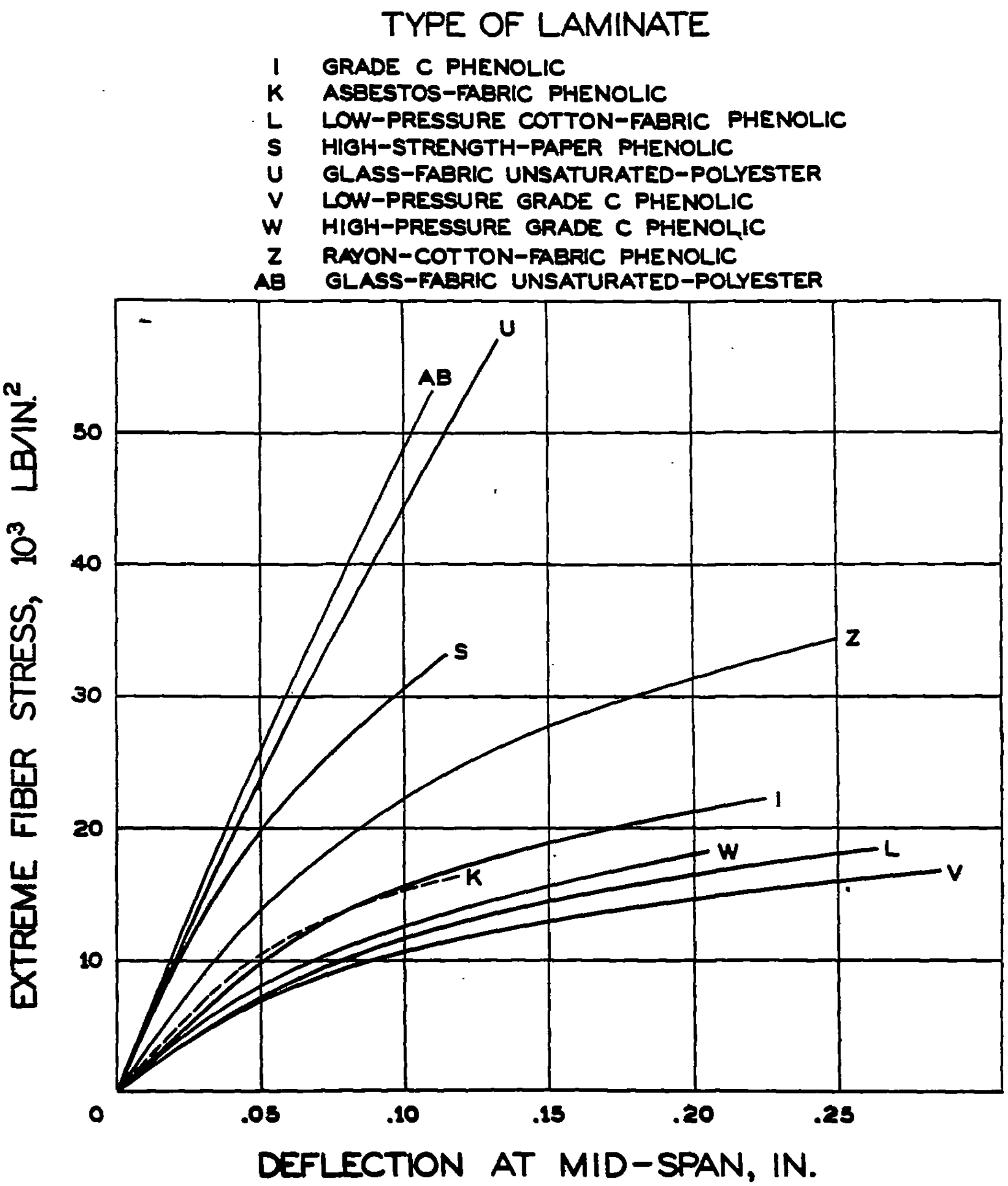

Figure 14.- Flexural stress-deflection curves for 1/2-inch-thick laminates at 77°F. Lengthwise specimens tested flatwise. Span-depth ratio 8:1.

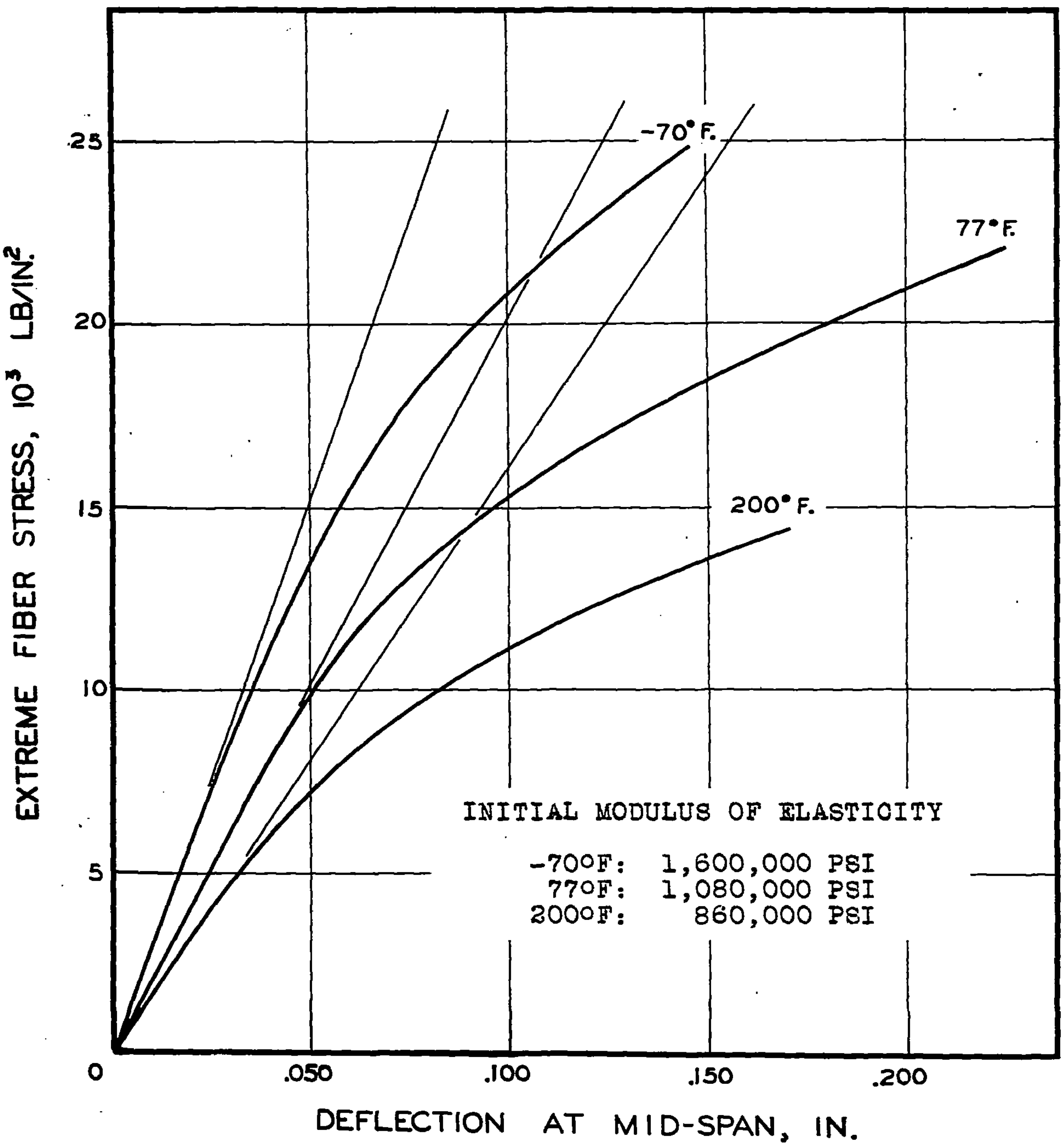

Figure 15.- Flexural stress-deflection curves for grade C cotton-fabric phenolic laminate, I2. Lengthwise specimens tested flatwise. Span-depth ratio 8:1.

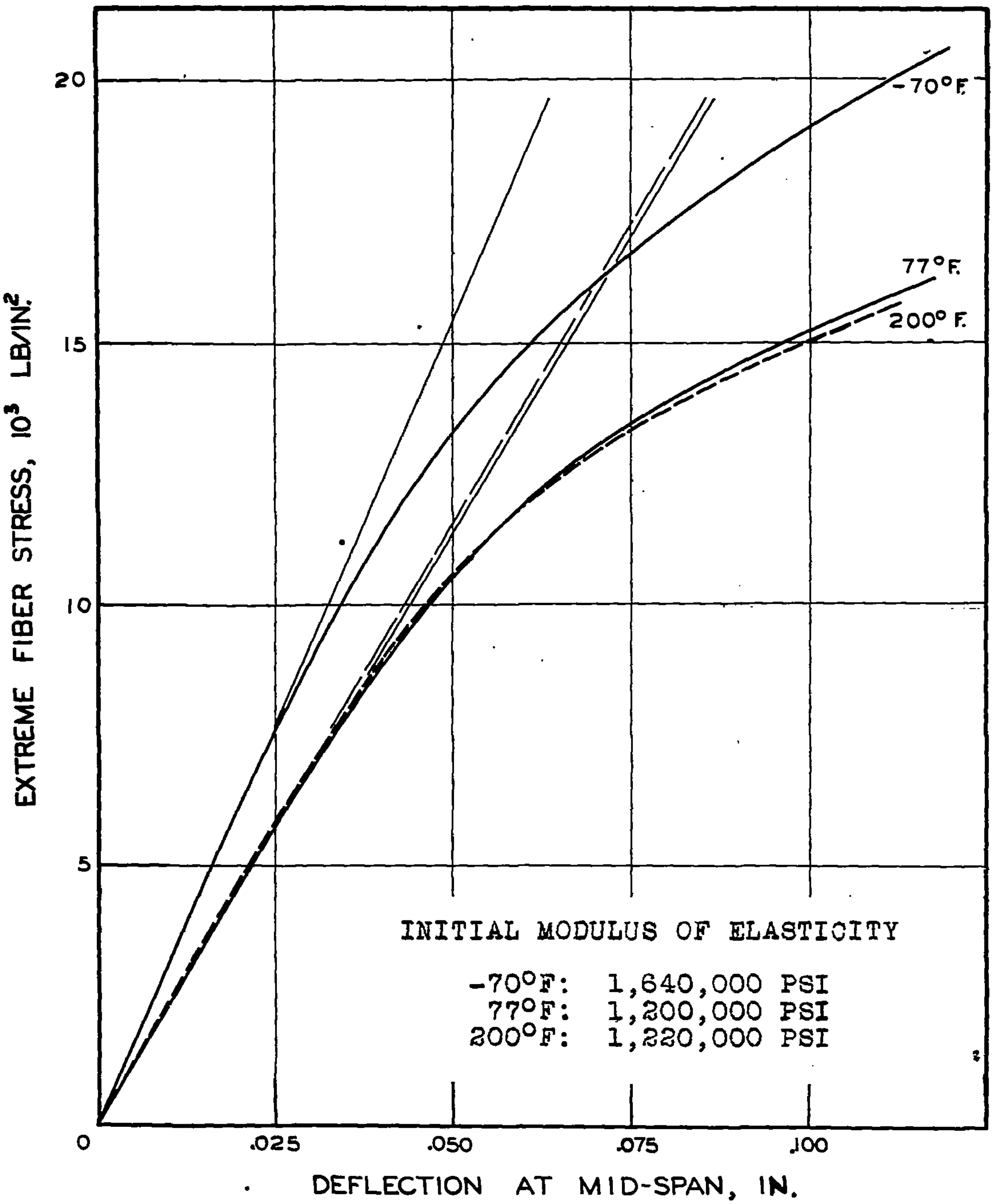

Figure 16.- Flexural stress-deflection curves for grade AA asbestos-fabric phenolic laminate, K2. Lengthwise specimens tested flatwise. Span-depth ratio 8:1.

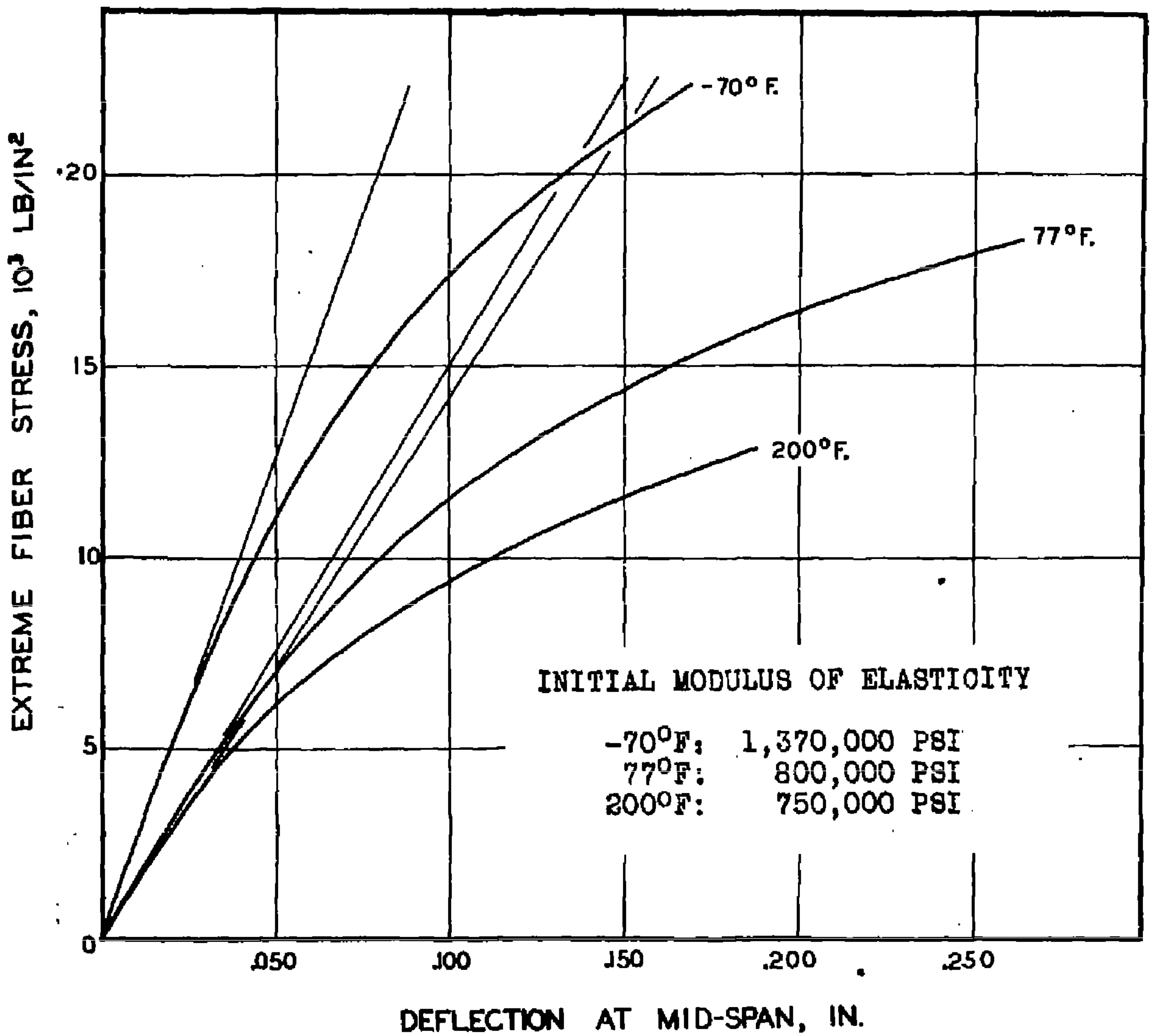

Figure 17.- Flexural stress-deflection curves for low-pressure cotton-fabric phenolic laminate, L2. Lengthwise specimens tested flatwise. Span-depth ratio 8:1.

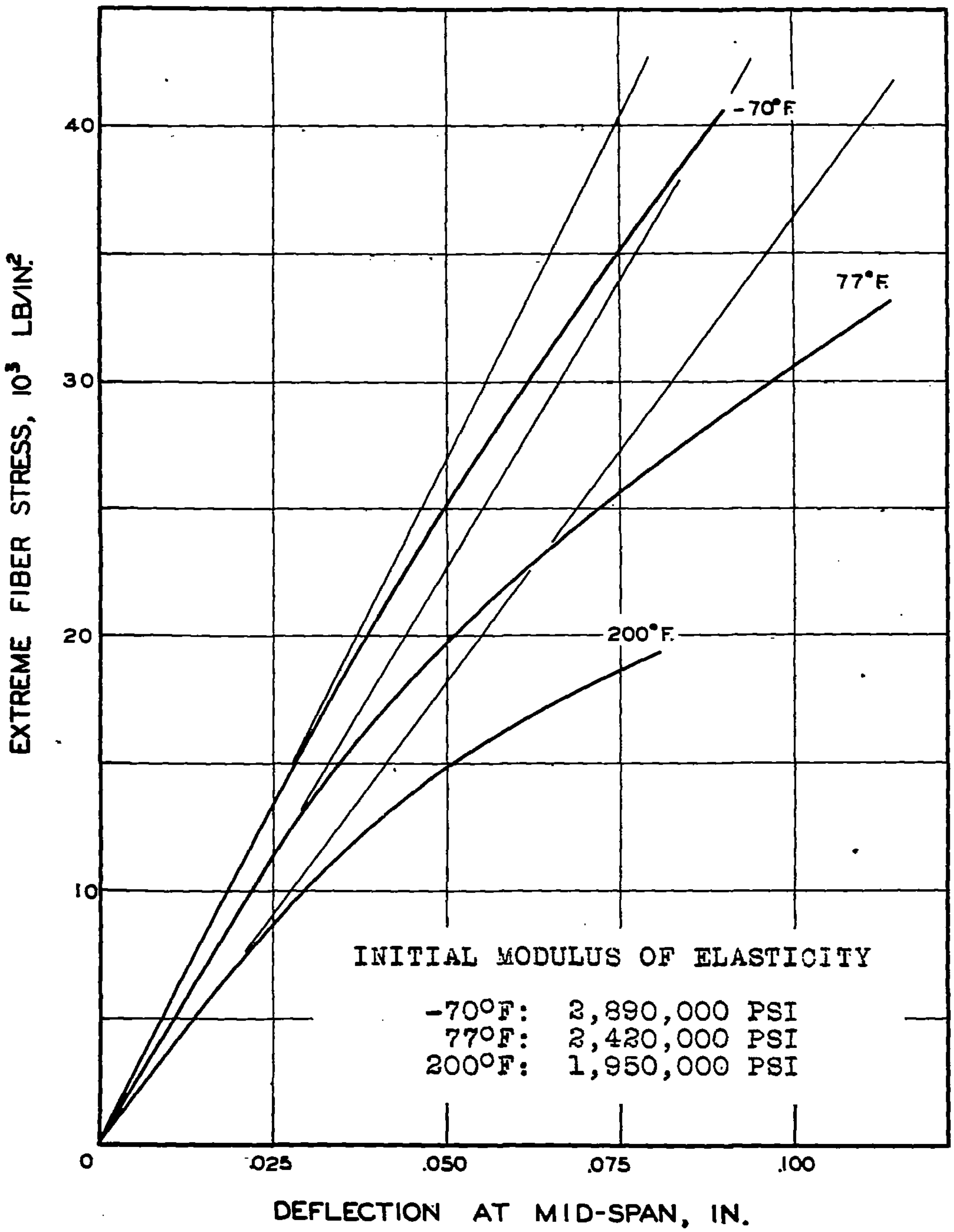

Figure 18.- Flexural stress-deflection curves for high-strength-paper phenolic laminate, S2. Lengthwise specimens tested flatwise. Span-depth ratio 8:1.

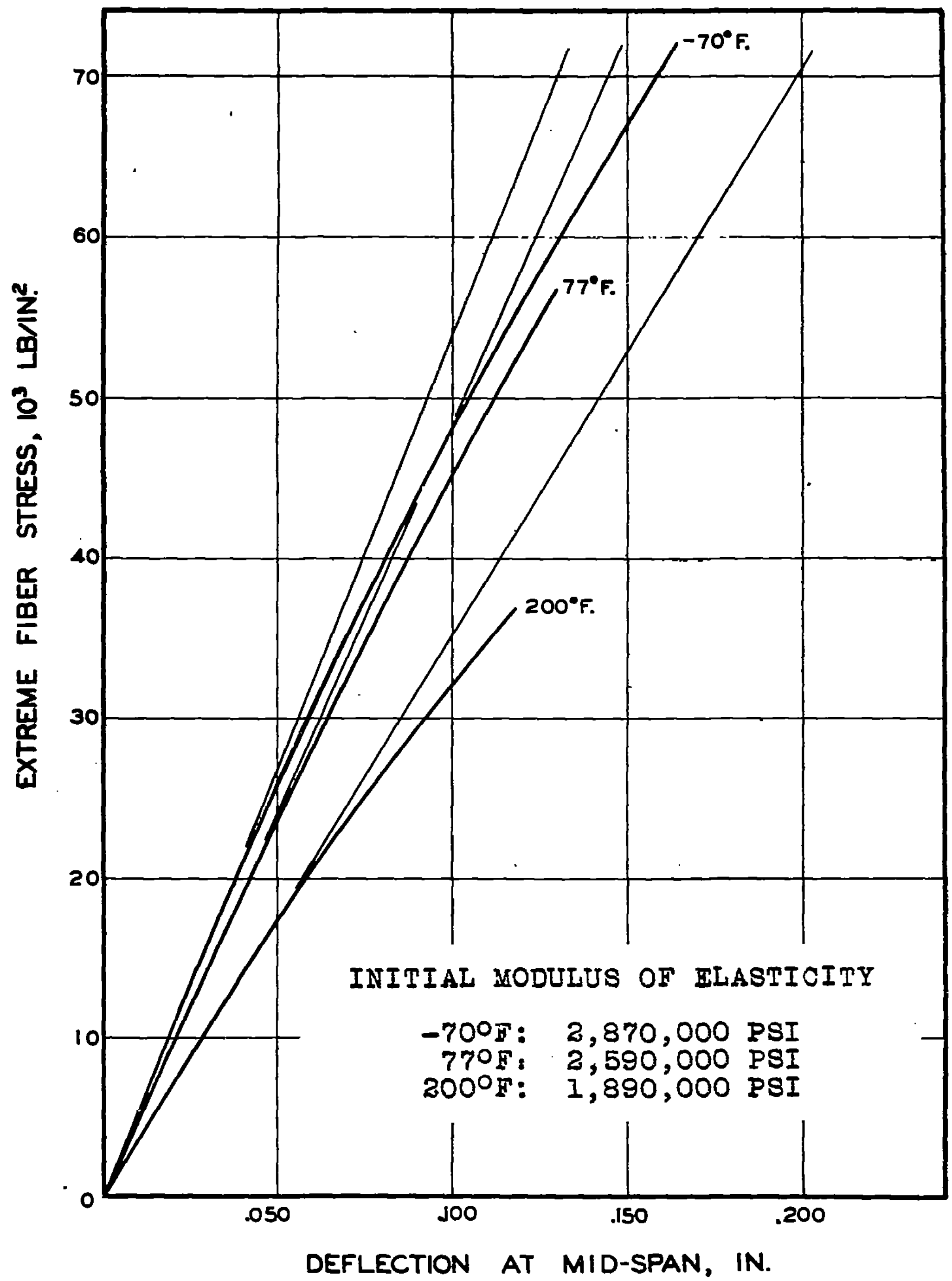

Figure 19.- Flexural stress-deflection curves for glass-fabric laminate bonded with unsaturated polyester resin, U2. Lengthwise specimens tested flatwise Span-depth ratio 8:1.

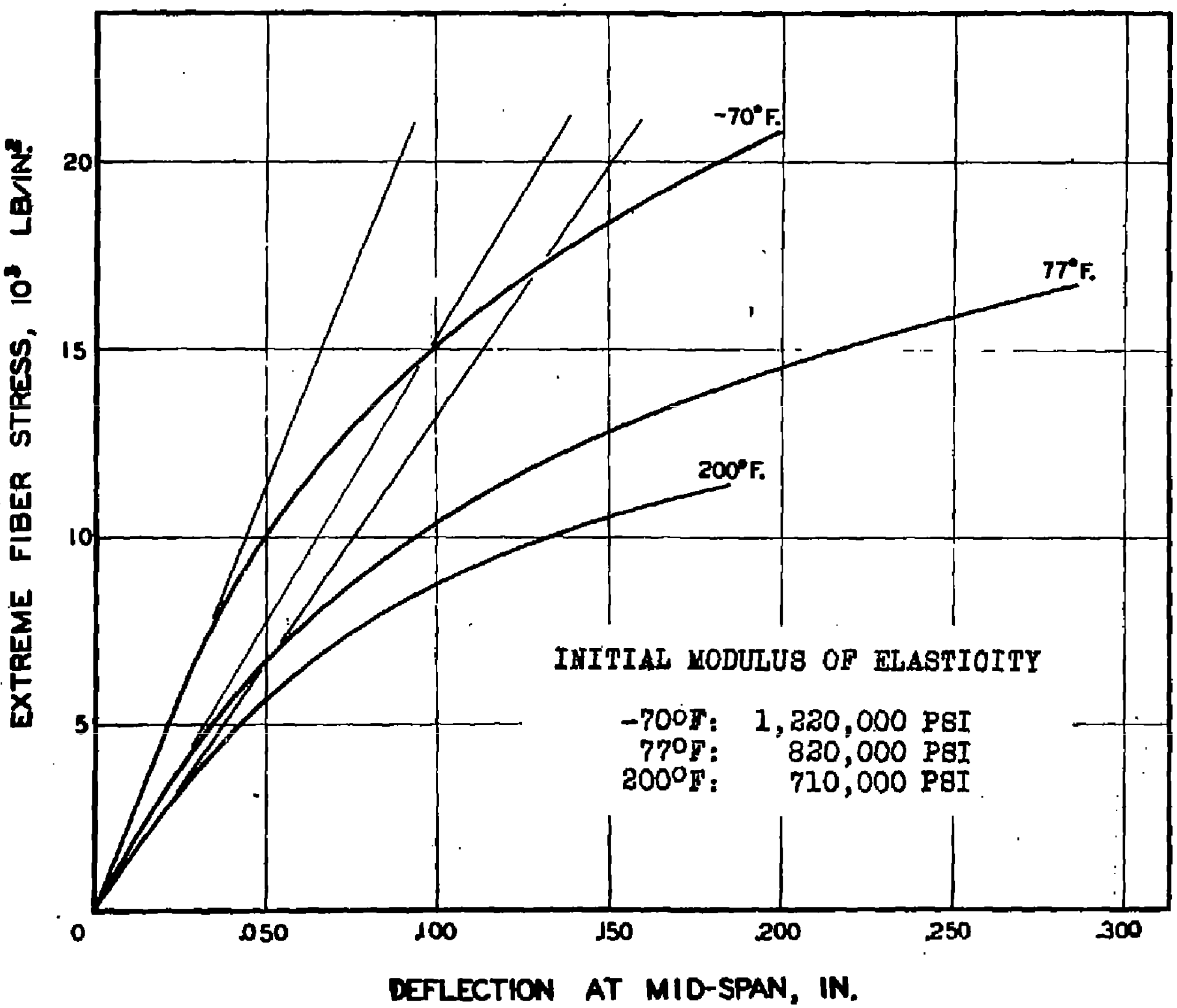

Figure 20.- Flexural stress-deflection curves for low-pressure grade C cotton-fabric phenolic laminate, V2. Lengthwise specimens tested flatwise. Span-depth ratio 8:1.

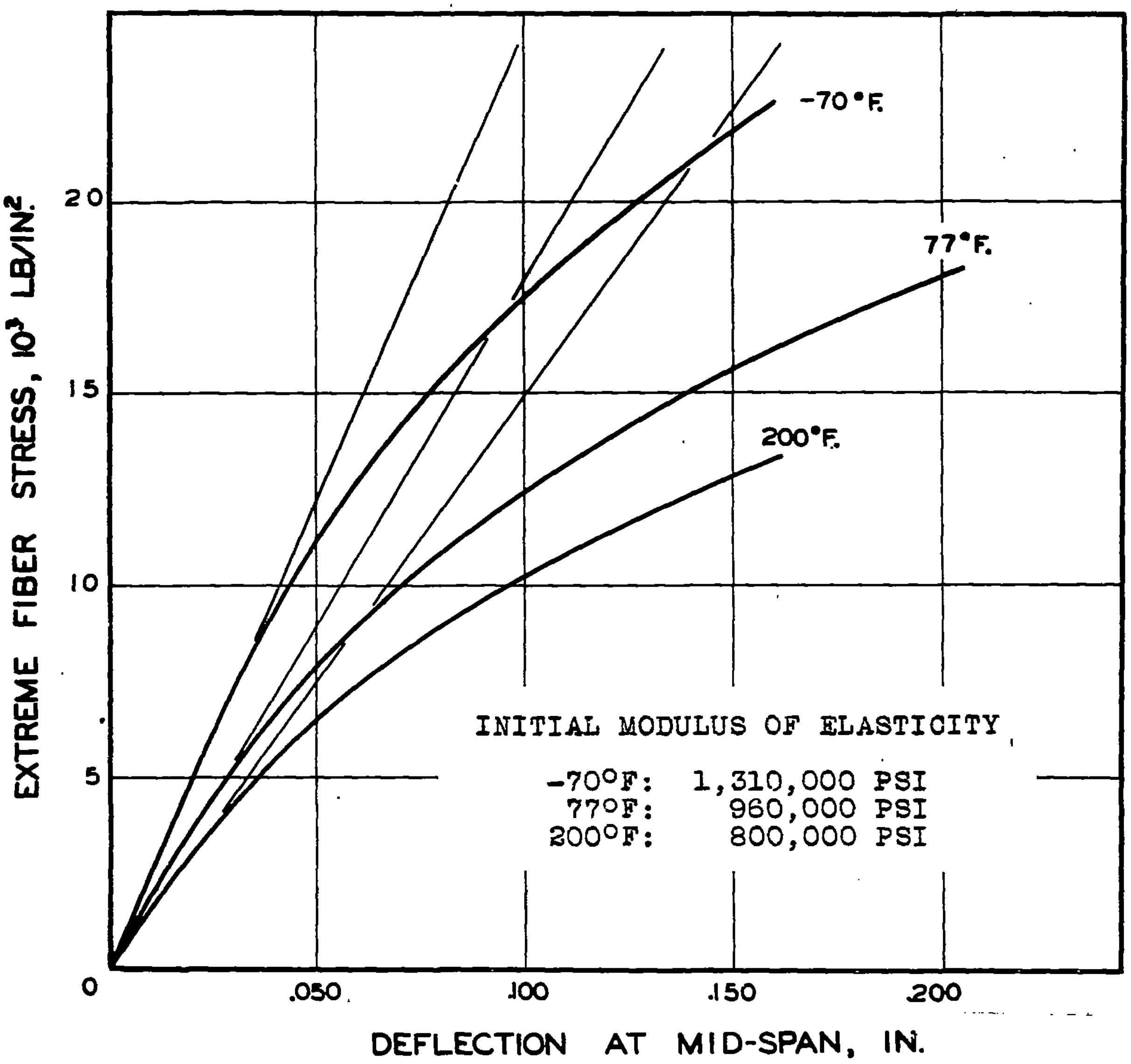

Figure 21.- Flexural stress-deflection curves for high-pressure grade C cotton-fabric phenolic laminate, W2. Lengthwise specimen tested flatwise, Span-depth ratio 8:1.

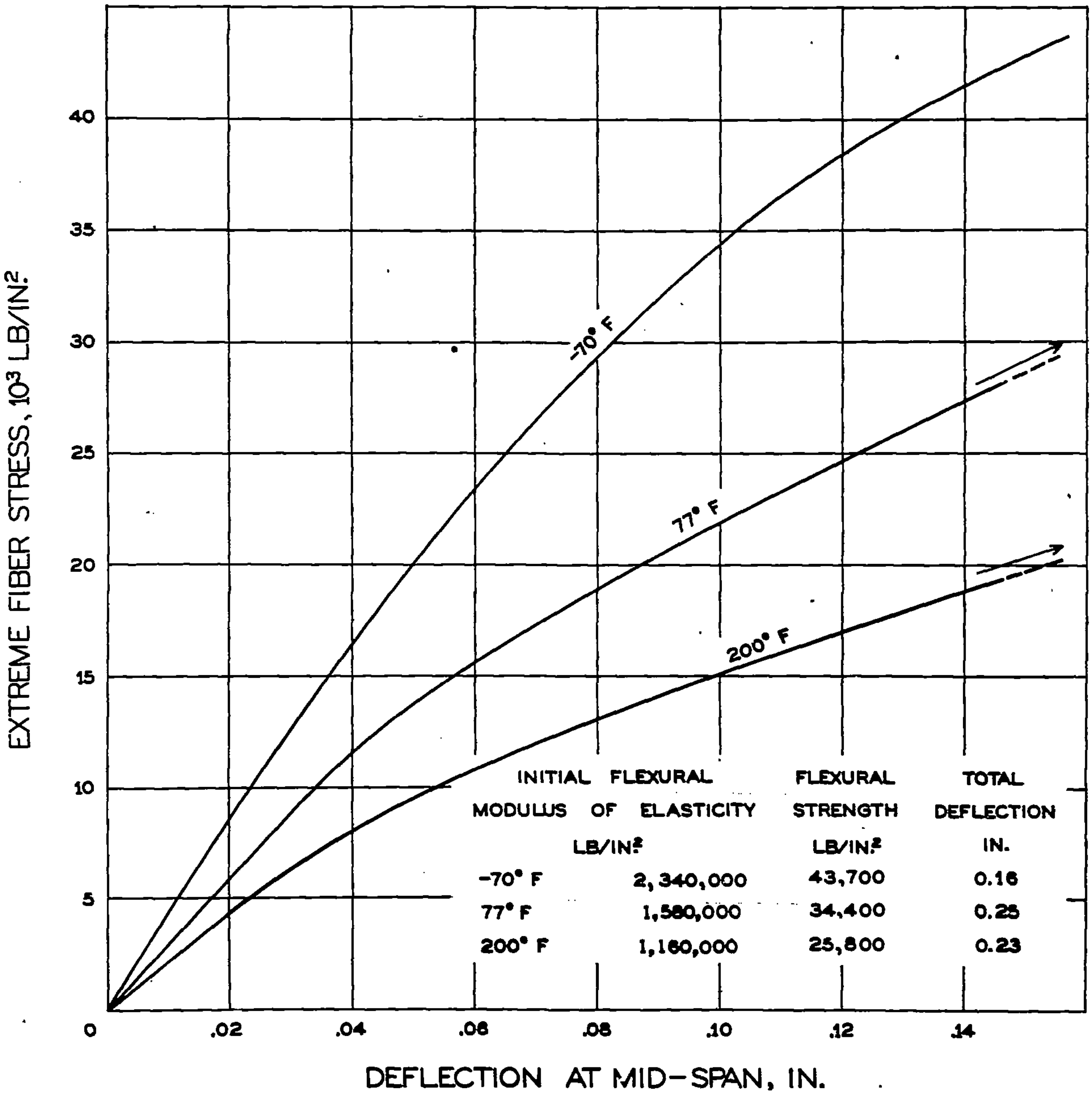

Figure 22.- Flexural stress-deflection curves for rayon-cotton-fabric phenolic laminate, Z2. Lengthwise specimens tested flatwise at three tempertures. Span-depth ratio 8:1.

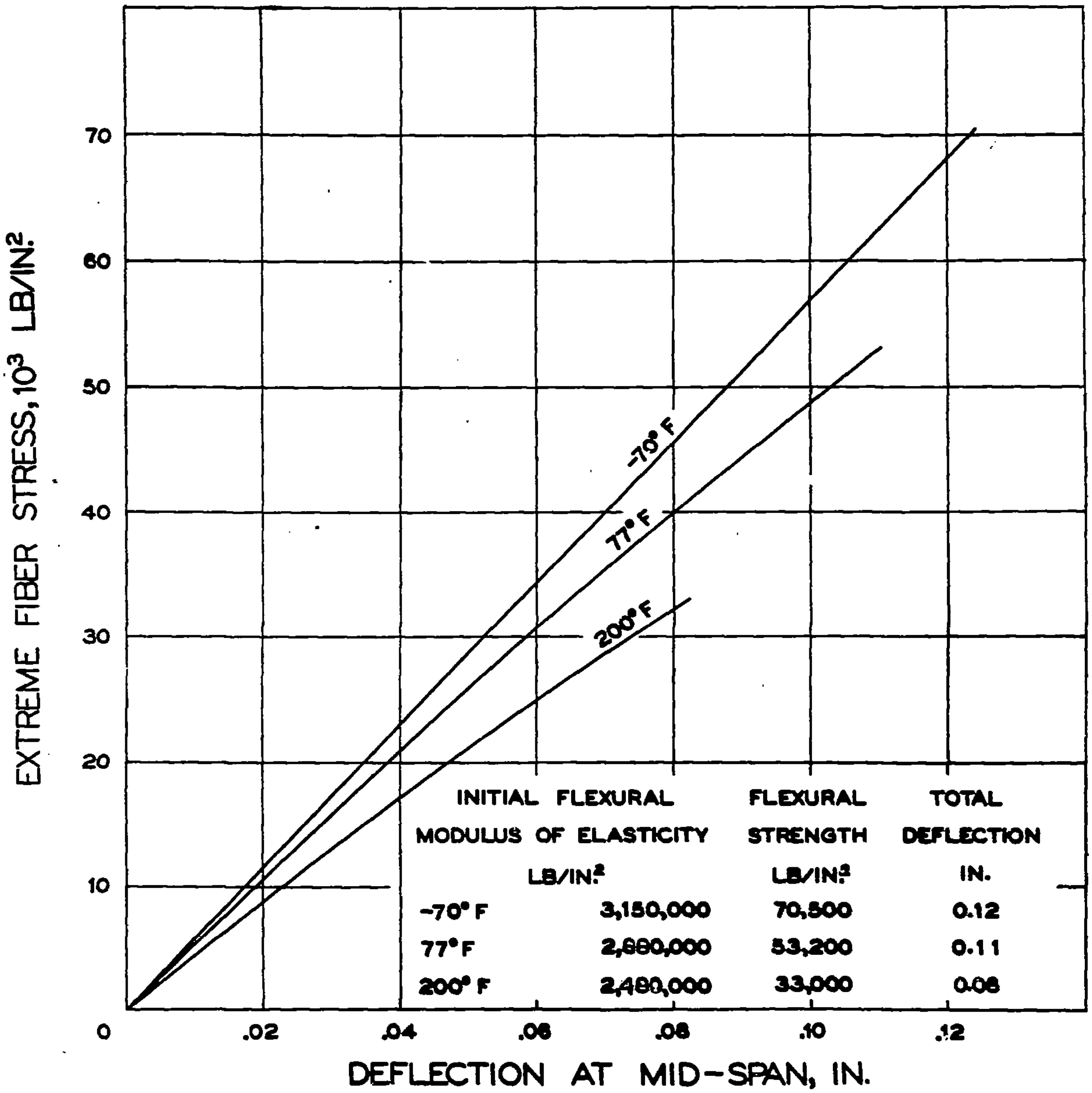

Figure 23.- Flexural stress-deflection curves for glass-fabric laminate, AB2. Lengthwise specimens tested flatwise. Span-depth ratio 8:1.

LF = LENGTHWISE SPECIMENS TESTED FLATWISE
LE = LENGTHWISE SPECIMENS TESTED EDGEWISE
CF = CROSSWISE SPECIMENS TESTED FLATWISE
CE = CROSSWISE SPECIMENS TESTED EDGEWISE

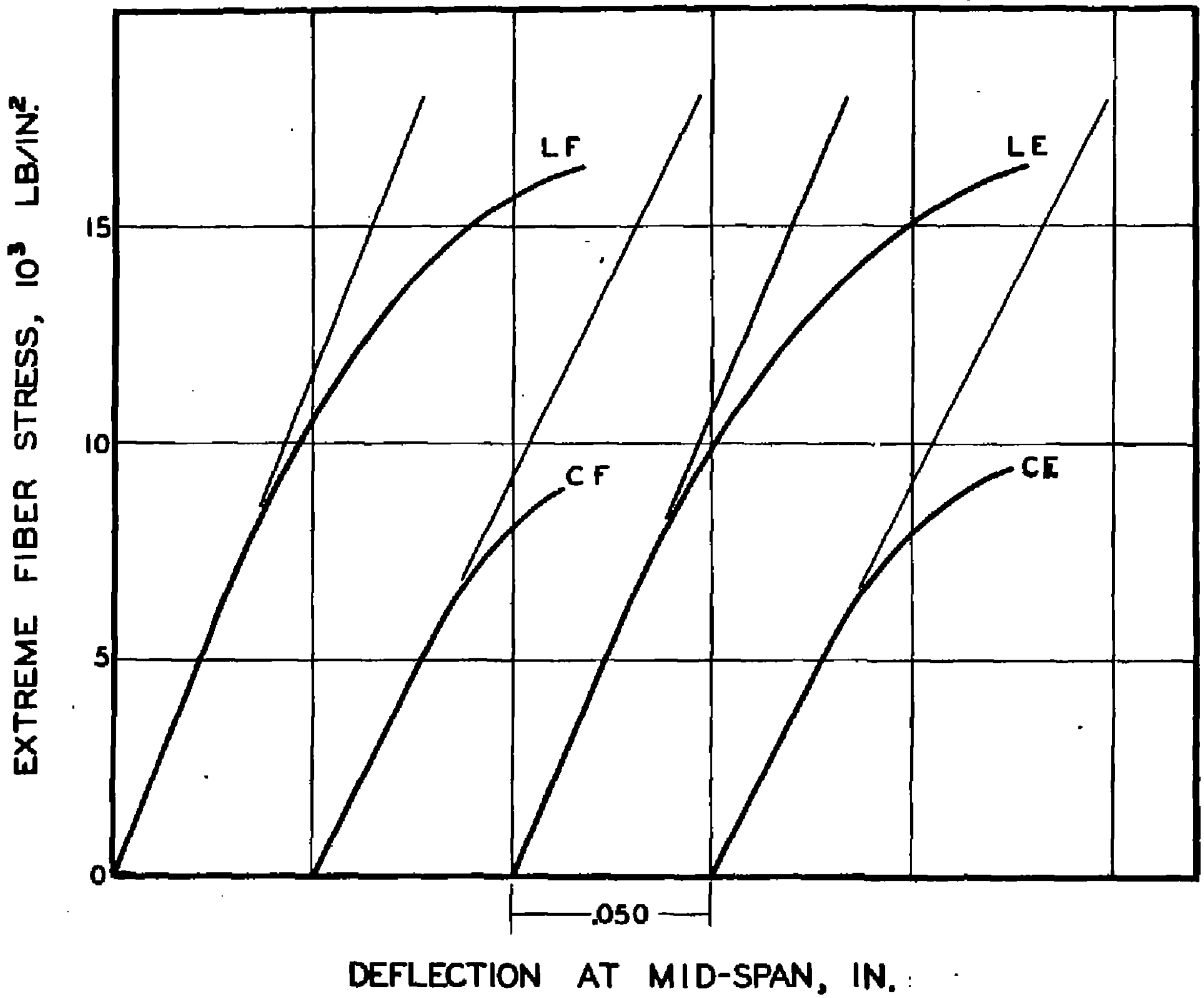

Figure 24.- Flexural stress-deflection curves for asbestos-fabric phenolic laminate, K2, at 77°F. Span-depth ratio 8:1.

LF = LENGTHWISE SPECIMENS TESTED FLATWISE
LE = LENGTHWISE SPECIMENS TESTED EDGEWISE
CF = CROSSWISE SPECIMENS TESTED FLATWISE
CE = CROSSWISE SPECIMENS TESTED EDGEWISE

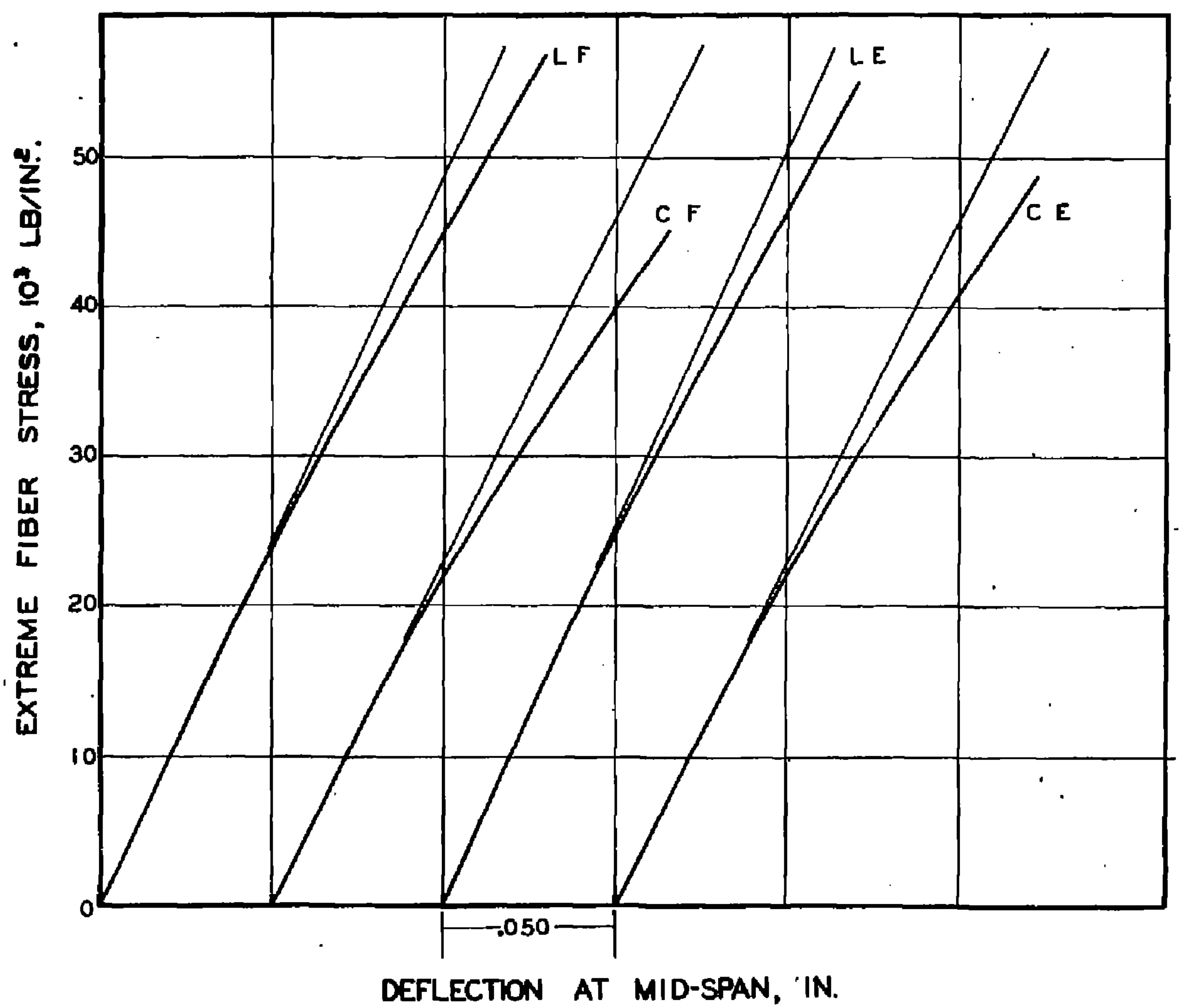

Figure 25.- Flexural stress-deflection curves for glass-fabric laminate bonded with unsaturated polyester resin, U2, at 77°F. Span-depth ratio 8:1.

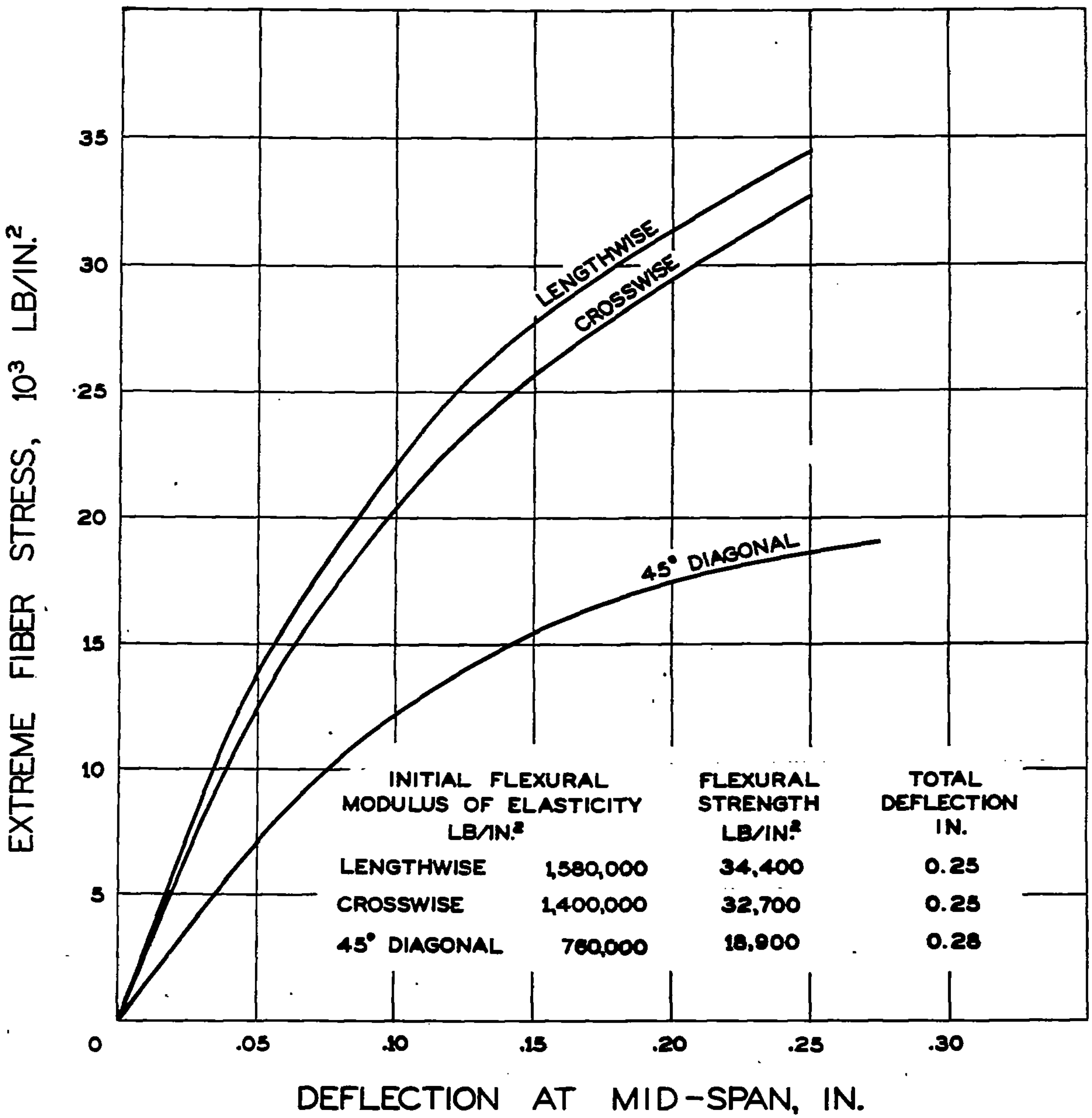

Figure 26.- Flexural stress-deflection curves for rayon-cotton-fabric phenolic laminate, Z2, tested flatwise at 77°F. Span-depth ratio 8:1.

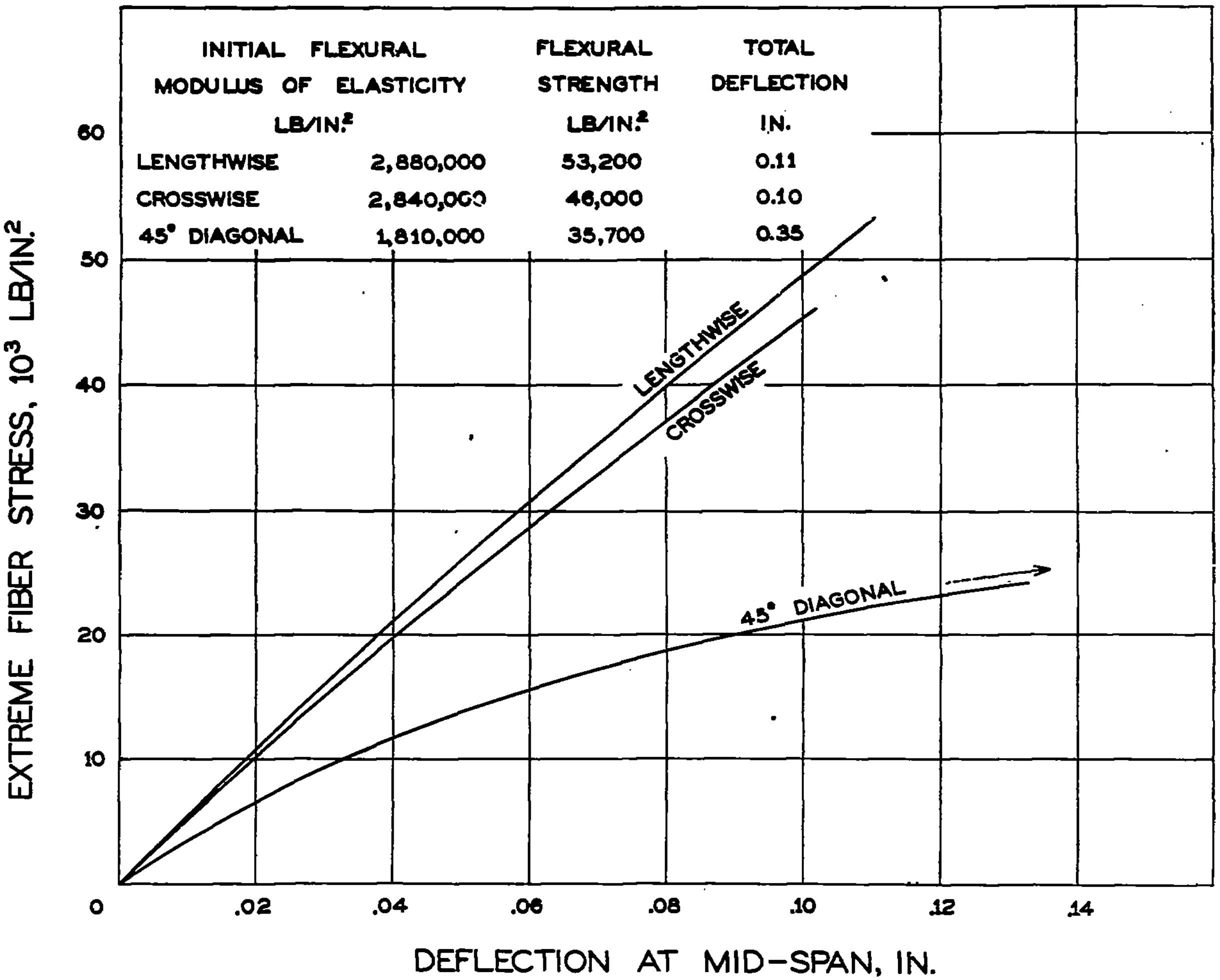

Figure 27.- Flexural stress-deflection curves for glass-fabric laminate, AB2, tested flatwise at 77°F. Span-depth ratio 8:1.

TSDIN FORM 69 (13 MAR 47)

R-8-2-14

ATI- 8007

ORIG. AGENCY NUMBER: TN-1054

REVISION

AUTHOR(S): Lamb, J. J.; Albrecht, I.

DIVISION: Materials (8)

SECTION: Plastics (2)

CROSS REFERENCES: Plastic materials (71942); Materiele, Laminated (60600); Strength of materials (90750); Plastics - Testing (71962); *

AMER. TITLE: Impact strength and flexural properties of laminated plastics at high and low temperatures

FORG'N. TITLE:

ORIGINATING AGENCY: National Advisory Committee for Aeronautics, Washington, D.C.

TRANSLATION:

COUNTRY	LANGUAGE	FORG'N.CLASS	U. S.CLASS.	DATE	PAGES	ILLUS.	FEATURES
U.S.	Eng.		Unclass.	Aug'46	58	38	photos, tables, graphs

ABSTRACT

Izod-impact strength and flexural properties of unsaturated-polyester laminates reinforced with glass fabric and of phenolic laminates reinforced with asbestos fabric, high-strength paper, rayon or cotton fabric were determined at temperatures from -70° to 200°F. Impact strength of specimens tested flatwise at 77°F was 4-7 ft/lb per in. of notch for all laminates, except those of glass fabric and rayon fabric. Flexural strengths and moduli of elasticity of all materials increased with change in test temperature. At 200°F, all materials, except asbestos fabric laminate, lost 30 to 40% of their flexural strength.

* Plastics - Physical properties (71959.5)

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